FERTILIZERS AND FOOD PRODUCTION

ON ARABLE AND GRASS LAND

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By

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With a Preface by

Sir HARRY McGOWAN

K.B.E.

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TO THE MEMORY OF

THE LATE

LORD MELCHETT, P.C., F.R.S.

FIRST BARON LANDFORD

AND TO

SIR HARRY McGOWAN, K.B.E.

CHAIRMAN OF IMPERIAL CHEMICAL INDUSTRIES, LIMITED

TO WHOSE FORESIGHT AND LEADERSHIP
JEALOTT'S HILL AGRICULTURAL RESEARCH STATION
OWES ITS FOUNDATION AND THE OPPORTUNITY TO
CONTRIBUTE TOWARD A CLOSER UNION BETWEEN
AGRICULTURE AND INDUSTRY
THIS BOOK IS DEDICATED
BY THE AUTHOR

PREFACE

BY SIR HARRY McGOWAN, K.B.E.

FORTUNATELY the country needs no convincing by me as to the great benefits that would accrue at the present time from a prosperous agriculture. Without prosperity —or at least solvency—it is idle to call upon the farmers to increase their production. Yet this call will most certainly have to be made, for an increase in the home production of foodstuffs with its corresponding decrease in imports represents one of the most important of the means available for redressing the national balance of trade.

It is a means moreover that inherently possesses a greater degree of permanence than an increase in visible or invisible exports. It has also collateral advantages in its effect on the social conditions and purchasing powers of the rural community as well as on the employment market and on the general stability and future security of the nation.

To what extent could the home production of foodstuffs be increased? The question is often asked, and many answers have been given. The truth is, of course, that the theoretical possibilities are almost boundless but the practical possibilities are definitely limited by the economic and political factors which must operate in this as in all other industries. Prices must be remunerative: the steps necessary to increase production must be capable of being carried out by the ordinary farmer without undue disorganization, and schemes for increasing production must be adopted which are best calculated to reconcile the interests of producers and consumers.

This is not the place to discuss the means whereby these conditions might be fulfilled. It is clear that increased efficiency in distribution and marketing is necessary and that some measure of protection or Government assistance is advisable to enable new organizations and new branches of production to develop. If remunerative price-levels and if confidence in their continuance over a term of years can be re-established, then increased and increasing production will normally follow.

This normal increase, however, will of necessity be slow, but there is one means of accelerating it which comes into operation in a single season, and which benefits the pocket of the farmer as well as the wealth of the nation—viz. the proper use of fertilizers. By the 'proper' use I mean the right kind of fertilizers in the right proportions, one with another, applied at the right time and in the right quantity, i.e. the quantity which yields the maximum profit to the farmer over and above the cost of the fertilizers.

It is the aim of the following pages to measure and set forth in detail the increase in production that could be achieved by this means alone. So far as arable crops for sale are concerned this increase is obtainable in one year, but with forage crops and grass land it should come more gradually, since to be profitable to the farmer it must roughly coincide with the increase in numbers of live stock.

It will be seen that the potential increase is startling in its magnitude, and that fertilizers properly used could make a really substantial contribution to increased production. When other factors are brought into consideration, such as better varieties and strains of seeds, higher cultivation by mechanical means, drainage and more frequent liming, then it is evident that in the fullest

possible development of the land—our greatest national asset—lies the most important and most fruitful task of our Government and our people.

The supposed antithesis of industry and agriculture is proved a fallacy: leaders of industry must join in ensuring for agriculture such support as will enable it to take the large share which it is capable of taking in the restoration of the country's well-being.

H. McG.

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THE aim of this book is to show that a large increase of home-grown food can be brought about—and brought about quickly—by means of fertilizers. The use of fertilizers is already a firmly established part of British farming practice. Those who farm intensively use them liberally and wisely. Market-gardeners, who cultivate still more intensively and who obtain yields far in excess of those to be got from farms, employ fertilizers with a yet more lavish hand. Nevertheless the application of fertilizers, even to arable land, though it has increased in striking manner during the last decade, has not grown so rapidly in this country as it has in many countries abroad; and so far as pasture land is concerned, the recognition that it also requires to be supplied continually with the essential plant foods which it lacks is of such recent origin that the right use of fertilizers on grass land has scarcely begun to be practised. It is true that one of the essential fertilizers, namely, phosphatic fertilizer, is widely used on grass land, but the no less important nitrogen fertilizers are not, and, until they are, grazing lands universally hungry for both phosphates and nitrogen will continue to contribute far less than they should to the food-supply of the nation.

The plan adopted in the book is to divide the problem of increased food production into two parts. Part I describes the way in which fertilizers may be used to increase food production in the immediate future: Part II shows the means by which food production may be further increased in the more distant, but by no means remote future.

In the first Part the plight and scope of British agriculture are described; the causes which have led to its present state are shown in operation during the past sixty years; evidence is brought forward to prove that fertilizers offer the most immediate and most effective means of increasing food production, and estimates are submitted of the amount of increase which may be obtained by their more sufficient and scientific use. The last chapter of Part I (Chapter VI) expresses the increases which should be obtained in terms of the additional augmented production of the more elaborate and expensive agricultural commodities—milk, butter, cheese, and meat. The figures of the estimate show that home production of food, now a little less than two-fifths of the total quantity consumed, could be raised in the near future to more than one-half, and that this country could look forward to becoming within a decade or so, all but self-supporting in milk, meat, and the other animal products of the farm.

Part II describes the further increases which would follow when a prosperous agriculture is able to take in hand the long-deferred work of draining and liming, which is essential to the restoration of soil fertility, and when the farmer's confidence of security is re-established and he can afford to apply in practice the accumulated results of agricultural research. With drainage and liming attended to, fertilizers would again intervene and would raise crop production to a yet higher level; improved grass-land management, paving the way for a rapid increase in the head of live stock, would cheapen the cost of production of milk and meat, and the conservation of surplus grass, now in large measure unattempted, would lead to even greater economies; meadow land would be made to supply

either in the form of ensilage or dried grass far more of the winter rations of cattle than it does at present; pasture, cultivated on a system of rotation akin to the rotation of crops on arable land, would lead to progressively richer and larger grazings.

The rate of increase in scientific knowledge of the use of fertilizers in maintaining and enhancing soil fertility would become accelerated, and with each addition, soundly based on science and well tried in practice, the fertility of the land would continue ever to grow.

> The flower must drink the nature of the earth
> Before it can put forth its blossoming.

The conclusions reached in the book can be judged in one way only. Preconceived opinions, even though they seem to be based on long experience, cannot disturb them. They must be judged by the evidence brought forward in their support.

It would have been possible to extend greatly the testimony given in these pages. Appeal might have been made more frequently to the evidence published by the numerous Research Stations with which, thanks to the far-sightedness of Sir Daniel Hall, Sir Thomas Middleton, and other members past and present of the Ministry of Agriculture, this country has been endowed. But a witness does well to confine himself to first-hand evidence, and the author has followed the precept. Whilst acknowledging in sundry places in the text the investigations of others, he has relied in the main on the trials and experiments made by the Staff of Jealott's Hill, both on the experimental farm, and on several hundred holdings and farms in Great Britain, Ireland, and elsewhere.

The recital of the evidence constitutes the greater part

of the book and therefore the book itself is to be regarded as the joint work of the Jealott's Hill Staff. They have shared with the author in the planning and execution of the programme of research now being carried out, and they have assisted in analysing the evidence provided by the experiments. Acknowledgement is made in the pages of the book of the assistance which the author has received from these, his friends and colleagues. Chief among them are Lt.-Col. Peel and Mr. H. J. Page, to whom the author's thanks are due in yet more abundant measure. As Head of the Research Laboratories, Mr. Page has had the arduous duty of co-ordinating the work of the laboratory with that of the Field Trials Staff and has shown that team work, well directed, can achieve results quickly, which isolated individuals, however gifted, must take long in getting. Lt.-Col. Peel has had chief responsibility for the numerous trials on farms and holdings, the results of which provide a remarkable illustration both of his own skill and enthusiasm and of the willingness of the British farmer to give time and trouble to putting into practice on the farm the discoveries made on an experimental scale. Lt.-Col. Peel, moreover, has been indefatigable in preparing the main body of evidence given in these pages, and in helping the author in the task of presenting it. Without his continued and generous help many of the pages of this book could not have been written.

All the author's colleagues and friends of the Research Staff own a co-authorship with him, and it is only because responsibility must rest on one head that their names do not appear on the title-page.

II

THE PRESENT POSITION OF AGRICULTURE

The Agricultural Industry of Great Britain and Northern Ireland. The decline of agriculture—1868 to the present day. Causes and consequences. The way to prosperity. Reforms needed. Soil fertility and fertilizers.

THE need for increasing home-grown supplies of food requires no emphasis. The bill paid by Great Britain for food[1] amounts to not less than £639 millions sterling. Of this total, £251 millions represent the value of the food produced and marketed at home, and £388 millions that of imported food: nor can the possibility be ignored that the sum required to pay for food imports in the near future may exceed this amount.

In prosperous times, with industry fully employed, the cost of imported food seemed to be a load lightly borne, but in these unprosperous times the yearly payment of such a sum as £388 millions becomes a grievously heavy burden, challenging inquiry whether or not it is necessary to continue to incur so large an expenditure and demanding an answer to the questions, can more food be produced at home and, if so, how much?

The Agricultural Industry of Great Britain and Northern Ireland. The present contribution made by farmers of Great Britain and Northern Ireland is little more than 38 per cent.;[2] the rest, nearly 62 per cent., comes from overseas. Looked at from this point of view, the part played by the British farmer may seem a small one; but not so when the actual amount of food which he produces

[1] *The Agricultural Output and the Food Supplies of Great Britain*, Ministry of Agriculture Publication, 1929.

[2] Measured in terms of the energy-producing power of foodstuffs.

is taken into account. That the farmer produces already a vast quantity of food is seen from the tables given in Appendix I. They show the amounts of the different sorts of food that he raises, the extent and productiveness of farming, and the kinds of farms and holdings on which food is grown. The essentials of these facts are illustrated in Chart I: an agricultural area of 48 million acres—31 in England and Wales, 14 in Scotland, and 3 millions in Northern Ireland. Of this area rather more than a quarter is arable land, three-eighths permanent pasture, and the rest rough grazings of poor grass on moorland and mountain side. Each year 4½ millions of the arable acres are under temporary grass, that is, grass sown down in the course of the rotation of crops practised on land under the plough. Six of the remaining 10 million acres of arable land grow cereals; oats occupying the largest, wheat next, and barley the least acreage. There are 1½ million acres used for roots (mangolds, &c.), three-quarters of a million for potatoes, and one-third of a million each for beans and peas, sugar beet, and fruit. The farms carry 35 million head of stock, namely, 8 million cattle, 24 million sheep, and 3 million pigs. The farms and holdings which do this work are for the most part small. Nearly four hundred thousand are holdings and farms of not more than 50 acres in extent: only one hundred thousand (one in six) are over 100 acres in extent.

Great Britain is already a country of small holdings: a fact which must be recognized in any national attempt to increase food production.

The people directly employed in farming number nearly one and a half million (see Table G of Appendix I), but to them must be added a very considerable company

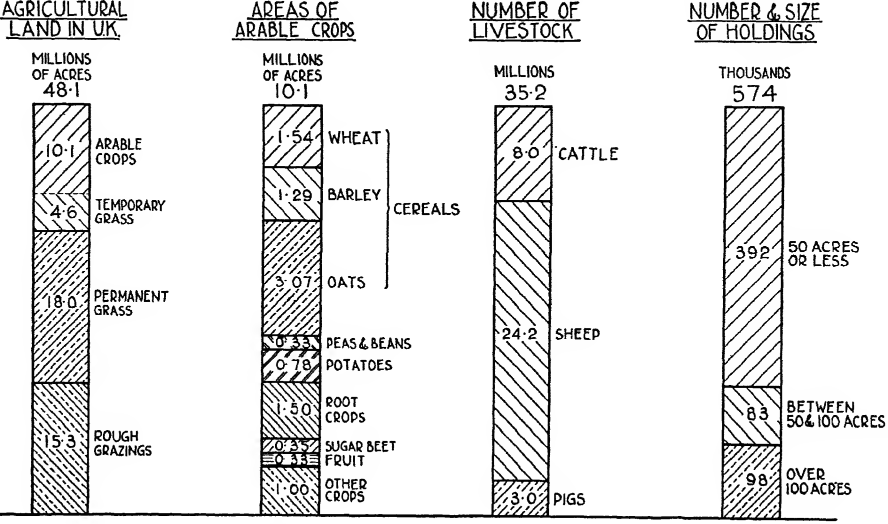

Chart I. The Present Scale of Agriculture in Great Britain and Northern Ireland

comprising all those of many and diverse trades and professions who are wholly or in part engaged in agricultural business. How many they are it is not possible to say, but they are sufficiently numerous to justify the opinion that unless agriculture is prosperous, the nation as a whole cannot enjoy permanent prosperity. No less true is it that unless prosperity can be restored to agriculture, it is useless to look to the farmers of Great Britain for any increase in food production whatsoever.

Fortunately it is not difficult to show that the present unprosperous state of agriculture is due mainly to causes which, although beyond the farmer's control, are nevertheless within the nation's power of remedy.

The decline of agriculture (1868 to the present day). Causes and consequences. A comparison of farming as it was in the middle of last century with farming as it is to-day reveals the nature of the causes which have led to the decline of British agriculture, and helps to show the steps which must be taken in order to make agriculture prosperous once again.

During the period 1868 to 1930 there came into full operation world forces which acted detrimentally on British agriculture. Chief among these forces were those released when new and rapid means of communication came into existence, making world transport, even of perishable goods, easy and cheap, and when simultaneously vast areas of new and virgin land endowed with age-long accumulations of fertility were opened up and brought under cultivation. So extensive and so naturally fertile were those new lands, and so cheap had transport become, that bountiful supplies of wheat, and presently other foods as well, soon became available for the feeding

of mankind. Indispensable for the growth of the ever-increasing industrial population, the new and cheap supplies boded but ill to the British farmer. He could not compete with them. As a consequence he grew less and less wheat. As a further consequence he was obliged to reduce the area under other crops, green crops and roots, which take their turn with wheat in the ordinary arable rotation. And so it came about that between 1868 and the present day 5 million acres of land ceased to produce arable crops—wheat, green crops including roots, &c.—and were either laid down or tumbled down to grass.

The result is that although the total area of agricultural land in Great Britain is much the same now as it was in 1868, the areas of arable and grass land have been interchanged. In 1868 there were 18 million acres of arable and 12 million acres of permanent grass: in 1930 the arable land had become less than 13 millions and the cultivated grass land had increased to more than 17 million acres.

The wheat lands have shrunk from upwards of 3½ million to the dangerously small area of less than 1½ million acres. The acreage under oats is now about 2¾ millions, that under barley is less than 1⅓ millions, and although the potato crop occupies the same area now as it did in 1868 the acreage devoted to green crops, roots, and the like is but little more than half what it was some sixty years ago.

With each impoverishment of agriculture the numbers of people employed on the land decreased, until there are now upwards of half a million fewer engaged in farming than there were at the beginning of the period.

The decline progressed in ever-widening circles. The

drier eastern areas of England, well endowed with land and climate for arable cultivation, suffered most. Before the decline began it was the custom there and in other largely arable areas to grow green crops, roots, &c., for the feeding of sheep. The pastoral farmer can graze his sheep for all or most of the year. The arable farmer, with less grass at his command, cannot. He folds them for a part of the year on arable land and feeds them with the green crops and roots which it produces. As the area under these crops shrank, many arable sheep had to go. There was less keep for them. The flocks, which were large and numerous in plough-land districts at the beginning of the period, dwindled in number and size; so that to-day the number of sheep in Great Britain is less by 7 millions than it was half a century ago.

The circle widens yet more! Sheep are pivotal of the agricultural system of the drier arable districts, such as those of East Anglia. They add both mechanically and chemically to the fertility of the land. Their even and frequent trampling consolidates it, making light land better for the growth of crops. They fertilize it, adding by their manure invaluable nitrogenous and other kinds of plant food.

The vicious circle drawn by circumstance is complete: less wheat; fewer green crops and roots; less food for folded sheep; 7 million sheep lost since 1868; an ever-dwindling rural population, a less fertile soil.

The full extent of these changes is told by the figures in Appendix II, which show how the decline has affected different parts of the country.

To illustrate how heavily the hand of misfortune has been laid on the arable farmer, the changes which have

taken place in an arable district may be compared with those in a district which is largely pastoral.

The *Eastern area* of England—a region of arable farming, comprises the eight counties, Bedfordshire, Huntingdonshire, Cambridgeshire, the Isle of Ely, Suffolk, Essex, Hertfordshire, and Middlesex. The *North-Western area*—largely pastoral—includes Cumberland, Westmorland, Lancashire, Cheshire, Derbyshire, and Staffordshire.

The *Arable area* shows the following changes:

	Arable acreage	*Sheep*
1868 . .	2,210,000	2,070,000
1930 . .	1,750,000	570,000

A reduction of 460,000 acres and of *1,500,000 sheep!*

The *Pastoral area*:

1868 . .	1,120,000	2,030,000
1930 . .	800,000	1,830,000

A reduction of 320,000 acres and of 200,000 sheep!

The loss of arable acreage is much the same in the two cases, but the consequences are very different. Of every ten sheep kept in 1868 the pastoral region still keeps nine; the arable less than four.

Dry climate and light soils were not propitious for the laying down of grass in the discarded arable land of the Eastern district and therefore the farmer could do no other than reduce his flocks. The more humid climate of the North-West gives better grass and there the farmer has been able all but to maintain his flocks.

But what of cattle? Has the loss of sheep been regained in cattle? A beast eats more and needs more field space than a sheep. It needs five times as much. When the two areas are again compared on the basis that five sheep

equal one beast, the shadows of the picture already drawn are deepened.

Eastern Area	*1868*	*1930*
Sheep	72	21
Cattle expressed as sheep	45	62
Total head of stock per 100 acres of arable and grass land	117	83

North-Western Area	*1868*	*1930*
Sheep	68	61
Cattle expressed as sheep	128	163
Total head of stock per 100 acres of arable and grass land	196	224

In the Eastern district a decline of 34 on every 100 acres of arable and grass land; in the North-Western district an increase of 28.

These increases and decreases would seem at first sight to bring some consolation, indicating as they appear to do a mere shifting of live stock from east to west. Facts refuse the consolation. During the period of decline, of the 5 million acres lost to arable some at least must have become available to the grazier. The total head of stock kept throughout the country should therefore show a marked increase. It does not. There are now some 1½ million more cattle than there were in 1868, but the loss of sheep sets off the gain in cattle. Counting the head of live stock in terms of cattle, each 100 acres of land which carried 38 head of stock in 1868 now carries but 39.

Nor even so is the tale complete of the misfortunes which have befallen agriculture. With falling prices and income ever shrinking the farmer could neither augment production nor pay so much heed as he would have liked to do to the other essential duty of the cultivator, namely, maintenance of soil fertility. What farmer to-day could afford to spend £16 per acre on the chalking of his fields,

as there were farmers wont to do in days shortly before William Cobbett went riding through the land. Liming, so necessary for soil fertility, has had to be neglected. It is nevertheless to the lasting credit of the British farmer that he has always endeavoured to keep the soil in good heart, and the nation owes a deep debt of gratitude to him for his continuous efforts to preserve the fertility of the soil which he cultivates. Circumstances fought against the farmer, and so he has only just been able to maintain crop production at a steady level; this he has done in spite of the fact that with dwindling resources he could not pay so much attention to those operations, essential to the maintenance of soil fertility, as his more prosperous forefathers were accustomed to do.

The maintenance of yields has been possible only because of the increasing use which has been made of fertilizers.

The picture outlined by these hard historical facts is a sombre one; wheat acreage reduced by one-half, barley by more than one-third, roots and green crops by a like amount; pastures, although increased in area, carrying few, if any, more live stock than they did fifty or sixty years ago.

Such are the far-reaching consequences to British agriculture which followed upon the opening up of new wheat and grazing lands during the latter half of the ninteenth century.

It would be a grave injustice to the agricultural community to imply that they have not made energetic attempts to arrest the decline in prosperity of their industry. They have. Pedigree stock have been maintained; large acreages in Kent and other counties suitable for fruit growing have been put under apples and other top fruit;

acreages as large have been laid down to the soft fruits; market garden produce has been greatly increased. The new crop, sugar beet, is being grown on no less than 300,000 acres; milk production has been increased. Enterprise, energy, fertility of resource have turned the tide of disaster from many a farmer's door. Courage and endurance have stemmed it, but ever and again with the fluctuations and falls of prices, the tide of disaster rises until it threatens to submerge the whole community.

No impartial critic with a knowledge of agriculture will lay the blame for his misfortunes on the farmer. Still less will any one with knowledge of recent discoveries in agricultural science conclude, because the recent agricultural past is gloomy, that the immediate outlook is also sombre. The truth is that until recently agricultural science did not know that none of these downgrade changes was inevitable. It now knows that those 5 million acres which were turned over from arable to pasture, if properly treated and properly managed, together with the arable that remained, could have been made to support just as many sheep as there were in 1868, and at the same time would have permitted of an increase in cattle far larger than that of 1½ millions which actually took place between the years 1868 and 1930.

The way to prosperity. Rightly apprehended the decline in agricultural prosperity is due to two causes. The prime cause lay beyond the farmer's power of remedy: a new fact—the larger production of cheap supplies of wheat and live stock from the new virgin lands of the world. A no less important cause of the decline, which also lay beyond the farmer's power of control, consists in the fact that at the time when he was confronted with the obliga-

tion to reduce his arable acreage, agricultural science did not possess the knowledge which could be used by the farmer to increase the productivity of grass land, and so compensate, and more than compensate, for the loss of plough land.

That knowledge is now available and will be recounted in subsequent pages of this book. Viewed in the light of this knowledge, the future of British agriculture is seen not to be gloomy but bright. If the nation can secure him from the dilemmas which have confronted him since the middle of last century, the farmer will by his skill and industry and by the application of the new knowledge increase the productivity of the land, and by so doing will add notably to the supplies of food raised in Great Britain.

Although consideration of the ways whereby the farmer is to be secured in obtaining fair remuneration for his labours lies outside the scope of these pages, it is relevant to show that the farmer possesses the ability and energy necessary to carry on the work of more intensive production of food. It is often assumed, because the farmer is experiencing hard times, that his difficulties are due to shortcomings as a cultivator and raiser of stock. If this assumption be put to the test it is found to be untrue. The crops produced by the farmers of Great Britain compare favourably with those raised by their skilled competitors. Table I contrasts the average yields of some of the chief crops grown in these islands with those of other countries enjoying somewhat similar conditions and climate.

Our farmers produce more wheat, oats, barley, and potatoes per acre than do either French or German farmers, and are beaten in crop production only by the Dutch. Moreover, as a breeder and raiser of live stock the

TABLE I

Comparison of Crop Production

	British Isles	*Germany*	*France*	*Holland*
Wheat, cwt. per acre .	17·8	14·7	11·3	22·8
Barley ,, ,, . .	15·9	13·7	11·4	23·3
Oats ,, ,, . .	15·0	13·6	10·8	15·4
Potatoes, tons per acre .	6·0	5·0	3·5	6·8
Sugar Beet, tons sugar per acre	1·25	1·5	1·5	1·8

NOTE. Average yields in the British Isles for the 10 years 1920–9 (sugar beet for year 1929 only) and for the 10 years 1920–9 for Germany, France, and Holland.

British farmer is admittedly pre-eminent. There is scarcely any part of the world that has not benefited by his extraordinary and wellnigh unique gift for improving the breeds of farm animals.

Reforms needed. Confronted with these facts and figures, no one can persist in asserting that the British farmer does not stand high among the cultivators of the world, and every one must admit that if the nation calls upon him to grow more food, he has ample skill wherewith to do it. That reforms would need to be introduced in the grading and marketing of produce, in agricultural education, in breaking down the isolation and moderating the conservatism which delay the application of new knowledge to farm practice, and no doubt in other directions also, go without saying. In addition to these reforms, the study of which can find no place here, there is one which must be mentioned and the need for which must be admitted. The average yields of crops are fairly high; but the best cultivators habitually produce yields far in excess of the average. Climate and soil help them, but their own

genius helps them more. If, as seems certain, these able cultivators—and they are very numerous—aid greatly in bringing up the average, there must be others—yet more numerous—at the other end of the scale whose food production is far too low. If, therefore, an increase in total production is required, energetic means will have to be discovered for helping the less skilled farmers to improve their output.

Two facts may be cited in support of this opinion. A recent investigation of over 300 Hertfordshire farms by the Cambridge Department of Agriculture showed that on more than one-quarter of the farms no fertilizers whatsoever were used. A recent tour of inquiry in Holland proved that there is scarcely a cultivator in that country who is either ignorant of the value of the different kinds of fertilizer or who neglects to use them judiciously and liberally.

With agriculture restored to prosperity, farmers generally, no longer hampered by insufficient means and uncertain prospects, will be quick to take advantage of better prices by enlarging their output. Their activities will take many different forms: farmers in arable districts will make it their first care to increase the yields of the cereal and other crops; some will go in more largely for pig-keeping, others will pay increased attention to poultry and egg production; more fruit will be grown; there will be a larger market for milk and dairy produce, and it will pay once again to specialize in the production of beef and mutton.

But if the agricultural community and the community at large are alike to benefit, if expenditure on imported food is to be reduced significantly, all this and something

more must be done. Care must be taken that increased production shall be got so far as possible from the land itself and not solely as the result of a larger use of imported feeding stuffs.

Soil fertility and fertilizers. The fertility of the land, both arable and grass, must be raised to and maintained at a higher level. Unless this be done, the agricultural prosperity which will be achieved will be a precarious prosperity, dependent to an undue degree on an increasing importation of feeding stuffs required for the raising and maintenance of the greatly increased flocks and herds which the land will be carrying. On the other hand, with every increase in its fertility the land itself will supply a larger proportion of the food required by the more numerous flocks and herds. Only if this condition is fulfilled can increased food production show a maximum of profit both to farmers and to the community as a whole.

The fertility of the land depends on many different factors, of which not a few are in large measure within the control of the cultivator. Some of these factors will be considered presently, but there is one which at the present time is by far the most important, and that factor may be summed up in one word: fertilizers.

Of the various means which may be used to increase home-grown food supplies and at the same time to raise the fertility of the land, some, indeed most, can be put into practice only gradually; but a more general and liberal use of fertilizers can increase food production immediately.

Jealott's Hill Research Station has been engaged during the past four years in studying by means of numerous large-scale experiments the ways in which fertilizers may

be used to increase food production and augment the fertility of agricultural land. As a result of these experiments, as well as those carried out at Rothamsted, Cambridge, Aberystwyth, Aberdeen, and other Research Stations, an important mass of knowledge established beyond all question is now at the disposal of the farmer.

It is true that large numbers of the more progressive farmers of this country are already applying this knowledge on their farms. It is not less true that there are many others who would apply it if they had the means to do so. But if there is to be a thrifty and large increase in home-grown food, every farmer must contribute his full share. This cannot be done unless all farmers understand the essential part that fertilizers play in food production, and make larger and more effective use of them than they do at present.

III

FERTILIZERS AND ARABLE CROPS

Fertilizers and crop yields. The outward and visible signs of soil fertility. Fertilizers bring profit to the farmer. The increased yields from fertilizers. Fertilizers on Recorded Farms. Market-garden yields. Fertilizers and crop production in Germany and Holland. High farming in the Holland Division of Lincolnshire.

Fertilizers and crop yields. The claims made in Chapter II must now be made good. They are, firstly, that by the more general and liberal use of fertilizers not only are larger crops obtained but also more milk, more meat, and indeed more of all the produce of the farm, and, secondly, that fertilizers offer the only means of making an immediate, large, and economic increase in food production.

There is only one way in which these claims can be made good, and that is by giving convincing evidence of the actual increases that have been obtained by the use of fertilizers, and by showing that increases similar in amount may be got from ordinary farm lands under average conditions.

The evidence concerning the increase to be obtained from arable crops is given in this chapter: that relating to pasture land in the following chapter.

The fertilizers with which crops must be supplied if they are to yield the maximum possible under the conditions of soil and climate in which they grow are chiefly of three kinds: nitrogen fertilizers, phosphates, and salts of potash. The natural supplies of these plant foods in the soil are, except in rare cases, not large enough to enable plants to yield heavy crops. Nor are the natural supplies

inexhaustible, and, therefore, fertilizers must be added to the soil to replace those which are removed by growing crops; otherwise the soil decreases in fertility.

The outward and visible signs of soil fertility. Deficiencies of the soil in nitrogen and mineral plant foods reveal themselves to the practised eye in the course of any journey in almost any part of the world. They may be seen in the growth of plants and in the colour of the landscape. A lack of nitrogen is shown by the plant in its size and colour. If the soil is extremely deficient in nitrogen, plants scarcely grow at all; if the deficiency is not so great, plants grow, but their leaves remain small and have a sickly yellowish-green colour instead of the full, deep green which is the sure sign of a soil rich in nitrogen plant food. When there is not enough potash, leaves, especially of such plants as mangolds and sugar beet, show brownish streaks or patches, and are apt to be brittle. If phosphates are lacking, plants do not ripen their fruits and seeds so well as they should, and their roots make none too vigorous development.

The landscape itself reveals the natural deficiencies of the soil. The traveller in South Africa looks almost in vain for the deep-green coloration which betokens nitrogen-plenty, and only when he visits the fruit-growing districts does he see in the almost black-green colour of the foliage of the orange groves that there at least is no stint in the use of nitrogen.

Returned home and journeying from England to Wales he passes through rich valleys where the grass betokens by its full green colour that it is amply supplied with nitrogen and the other plant foods—thanks to the washing down from the hill-sides of these substances and their accumulation

in the lower-lying ground. But on the hill-sides themselves the lighter green colour of the herbage and the lack of the emerald tone show the traveller at a glance that all the high lands are suffering from a shortage of phosphates. And wellnigh every hill-side and stretch of downland in England betray by the brownness or ashen greyness of the landscape in spring that there also plant life, though already the magic quickening touch of spring has been laid upon it, awaits before it can awaken from its winter lethargy the no less magical touch of nitrogen. There may be seen to-day high upon Plinlimmon bright green patches which stand out all the winter in contrast with the surrounding pale brown grass. They are parcels of grass land on which Professor R. G. Stapledon, of Aberystwyth, has been experimenting in order to find out whether these rough grazings, so inherently sterile that they can support only one sheep to the acre or even less than that, may not also be made fertile by the application of nitrogenous and phosphatic fertilizers. Their colour is a sign of response to these fertilizers and an augury of hope that the hill lands may yet be made fertile.

In many apple orchards in England the leaves turn brown prematurely and the fruit which the trees bear is undersized. Stunted fruit and brown-flecked leaves alike testify to lack of potash in the soil. Experiment has shown that when the deficiency is made good the leaves keep their natural greenness, and the little apples give place to big ones. In the apple orchards also any year sees many trees fruitless; many kinds of apple left to themselves have their 'off' and 'on' years alternately. Unaided by the addition of nitrogen plant-food to the soil, the work of the trees in fruit-bearing makes such a heavy draft on such stores of

nitrogen as they possess that next year the leaves are smaller and do their work so ill that there is little fruit; but if in each spring a quick-acting nitrogen fertilizer is added to the soil, there are no 'on' and 'off' years; the apple trees bear crops regularly year after year.

The film of the earth which is called the soil, on which all life depends, though marvellous in its perennial powers to sustain the lives of all the plants and beasts and men of the world, needs careful management and generous treatment if it is successfully to play the part of Atlas and bear the burden of an ever-growing world of living things.

Under an impoverished system of agriculture only the more fortunate farmers can afford the expense of ensuring that the soil which they cultivate shall contain ample supplies of the essential food materials.

It is therefore inevitable that much of the land of this country should be suffering from insufficiency of plant food. Most cultivators and all scientific agriculturists are aware of it, and farmers generally will take steps to remedy the deficiency when they can be reasonably confident that their outlay on fertilizers will be remunerated by the price which they receive for the larger crops.

Fertilizers bring profit to the farmer. Fortunately the price of fertilizers is, and is likely to remain, at a level which will pay the farmer who uses them. Ample supplies of nitrogen fertilizers manufactured in this country are available for the farmer's use, and the producers of the synthetic and by-product nitrogen fertilizers desiring, as they do, to see them much more largely used, will undoubtedly exercise all the powers at their command to make the large use profitable to the farmer. Supplies of phosphates are also available from home sources, although

in quantities insufficient to supply all the requirements of the land. Potash fertilizers have to be imported. The sources of supply are, however, so numerous as to ensure also with respect to these fertilizers that the prices will remain at levels generously remunerative to the farmers who use them.

With the industry restored to prosperity, the farmer will be able to cultivate more thoroughly the land under the plough. With every betterment of cultivation the returns in crop yields which he obtains from fertilizers will be increased; for without thorough cultivation of the land the crop-increasing powers of fertilizers are not fully exercised. Nevertheless, the estimates given in Chapter VI of the increases in food supplies which can be brought about by the use of fertilizers make no allowance for this important source of further improvement. The land is taken as it is; its present yields are set forth, and the immediate increases which may be expected are shown.

The increased yields from fertilizers. Accurate experiments on the effect of fertilizers in increasing yields of crops have been carried out for many years in almost every civilized country of the world, and nowhere more thoroughly than in this country. Of the many experiments which have been made in Great Britain, the most famous are those carried out at Rothamsted under the successive direction of Sir John Lawes, Sir Henry Gilbert, Sir Daniel Hall, and, since 1912, Sir John Russell. They were begun by Sir John Lawes, who was one of the first to understand the importance of fertilizers, to set up plant for manufacturing them, and to experiment in their agricultural uses. The Rothamsted experiments commenced in 1843 have been continued to the present day. They have given

results of the greatest importance to agriculture, and every year sees increase in their value.

The classical Rothamsted experiments and the more recent ones since carried out there and elsewhere give accurate measures of the increase in yield of the chief arable crops which are got by means of fertilizers. Those about to be quoted give the results in terms of one fertilizer only, namely, nitrogen fertilizer, but it has to be borne in mind that nitrogen produces its full effect only when used in suitable conjunction with the mineral fertilizers—phosphates and potash salts. Indeed it cannot be too fully realized that no one of the three fertilizers is replaceable by another. Each has its special part to play in the life of plants, each enters into the living fabric of the plant, and it is therefore as foolish for any one to believe in the exclusive efficacy of a single one of the three as it is to believe that one of its legs alone supports a three-legged table.

The results of the Rothamsted experiments are shown in Table II.

TABLE II

ROTHAMSTED[1]

Increased Yield expected from 1 cwt. Sulphate of Ammonia per acre where sufficient Phosphate and Potash is given in the Rotation

Potatoes	20	cw
Mangolds	32	,,
Swedes	20	,,
Barley	3·2	,,
Oats	2·6	,,
Wheat	2·5	,,
Meadow hay	9	,,

The conclusions to which the figures point are confirmed by experiments carried out (Table III) by Mr. Page,

[1] Rothamsted Experimental Station Report for 1929.

Mr. J. Procter, and the Field Trials Staff during the past three years at Jealott's Hill. As is the case with the Rothamsted experiments, they were made on soils which received not only nitrogen fertilizer but also adequate supplies of phosphates and potash. Appeal will be made to both sets of experiments when estimates of the possible amount of increased crop production come up for discussion.

TABLE III

JEALOTT'S HILL

	No Nitrogen	With Nitrogen		Increase due to 1 cwt. sulphate of ammonia or equivalent
	Yield per acre	*Nitrogen per acre*	*Yield per acre*	
	tons	lb.	tons	cwt.
Potatoes	9·85	60	12·49	20·2
Mangolds	20·4	47	25·7	51·9
Sugar beet (sugar per acre)	1·77	55	2·45	5·7
	cwt.		cwt.	
Barley	20·1	31	25·1	3·7
Oats	17·3	32	22·6	3·8
Wheat	25·6	34	29·6	2·7
Hay from temporary grass	62·4	23	73	10·6

The accuracy with which field experiments are now made, and the mathematical precision with which the results are analysed before conclusions are drawn from them, ensure that complete reliance may be placed upon them. Nevertheless, there is always a natural hesitation among farmers to accept results obtained from small areas of land as evidence of what will happen when they are applied on a large scale on the farm. Recognizing that this criticism is bound to be made and must be met, the staff of Jealott's Hill have carried out, in co-operation

with farmers, numerous experiments on a large scale on farms.

Fertilizers on Recorded Farms. The arable land of nine farms, a total area of 2,500 acres, supplied the ground for the experiments. The farms themselves were chosen not from those of high fertility or fortunate position, but as being fairly representative of many arable districts of England. They are situated in the following counties: East Yorkshire, Norfolk, Cambridge, Essex, Sussex, Gloucester, and Shropshire. The experiments took the form of applying dressings of fertilizers larger than those used in the neighbourhood. The average yields of the crops on the Recorded Farms in the years 1928, 1929, 1930 are contrasted in Table IV with the average yields obtained throughout England and Wales.

TABLE IV

Yield of arable crops on Recorded Farms compared with average for England and Wales, 1928–30

	England and Wales	*Recorded Farms*
Wheat	17·7 cwt. per acre	22·0 cwt. per acre
Barley	16·5 „ „	19·6 „ „
Oats	15·9 „ „	20·22 „ „
Sugar beet . . .	8·4 tons „	10·5 tons „
Potatoes . . .	6·9 „ „	7·3 „ „
Mangolds . . .	19·1 „ „	24·5 „ „

As the Table shows, excess of production per acre on the Recorded Farms over the average production in England and Wales is:

4⅓ cwt. wheat.
3 cwt. barley.
4⅓ cwt. oats.
2 tons sugar beet.
5⅓ tons mangolds.

Potatoes alone gave a disappointing increase (8 cwt.), but with respect to this crop it is only fair to say that none of the Recorded Farms is in a potato-growing district.

In order that the results may be used for another purpose they are expressed in Table V as *percentages* of the average yields for England and Wales. The yields of the Recorded Farms are higher than the average for England and Wales by the percentages shown in Table V.

TABLE V

	Results of Recorded Farms per cent.	*Jealott's Hill Results per cent.*
Wheat	24	15½
Barley	19	25
Oats	27	30½
Sugar beet	25	38
Mangolds	28	26
Potatoes	6	27

Stated in this way the results allow of comparison with those which express, also in percentages, the yields obtained in the Jealott's Hill experiments.

The general run of the two sets of figures is so close that the results must be regarded as confirming one another, and since in either case the increases always occur in the crops which received liberal dressings of fertilizers, the conclusion cannot be escaped that the increases are due to the fertilizers and nothing else.

There are, however, other ways in which this conclusion may be put to the test.

Market-garden yields. It is a well-known fact that farm crops grown under market-garden conditions produce far larger yields than do the same crops grow-

conditions. The smaller acreage, the specially selected soil and situation, and the more intensive cultivation, all assist in bringing about the larger yields. But the liberal use of manures is an essential factor in securing them. Many examples of the almost incredibly high yields which are obtained when specialists engage in the cultivation of a single crop might be given. The market-gardener who farms most intensively incurs such heavy expenses that a crop often does not begin to pay until it has brought in a return of £200 to the acre. The use of fertilizers is therefore a relatively small charge on the crop. The market-gardener uses them lavishly and obtains in the increased returns yields far in excess of the cost of fertilizers. The yields which he gets are very large. For example, the increase of a crop of spring cabbage due to heavy dressings of fertilizers was measured by comparing yields from fertilized and unfertilized areas. The soil in which the experiment was made was a sandy loam. The untreated area gave a crop of rather less than 8 tons to the acre, whereas that adjoining it, which received liberal supplies of phosphates and potash and the equivalent of 8 cwt. nitrogen fertilizer to the acre, gave 14 tons; an increase of 75 per cent.

The rhubarb crop, an important one in the rotation practised by many market-gardeners, if sufficiently early and heavy, may bring in to the grower for the two years during which it is on the ground so much as £450 per acre; a gross annual return of £225. To obtain yields large enough to give returns such as these the grower is lavish both in the use of farmyard manure and in the quantities of fertilizers which he applies to the land. In some cases so much as 80 tons of farmyard manure is used. Accurate measurements of yield of rhubarb brought about by an

increasing use of nitrogen fertilizer show in round numbers; when 1 cwt. of nitrogen fertilizer was applied, 18½ tons. An additional cwt. given as a top-dressing gave nearly 24 tons, two top-dressings of 1 cwt.—3 cwt. in all—yielded nearly 27 tons, and three dressings gave over 30 tons.

It has been customary for some years past to encourage the use of fertilizers among the small growers of potatoes in Ireland. Accurate measurements of yield are made and prizes are given to producers of the biggest crop. The maximum yields (see Table VI) which are obtained are generally not less than four times those got on the average farm of Great Britain. Instead of the 6⅓ tons of potatoes to the acre (the average for Great Britain) the prize-winners are disappointed if they cannot boast a crop of well over 20 tons to the acre.

Needless to say, these colossal yields are not attainable under ordinary farm conditions, but even on the farm in potato-growing districts—the Lothians of Scotland, Lincolnshire, and elsewhere—yields twice as large as the average for Great Britain are frequently obtained and not infrequently exceeded; a fact which cannot fail to evoke the question whether much might not be done to raise the average yields of farm crops if land unsuitable for heavy arable cropping were put to other more profitable uses!

TABLE VI

Yields per Acre of Potatoes. Small Areas Intensively Cultivated

	Irish Free State			*Northern Ireland*		
	tons	cwt.	qrs.	tons	cwt.	qrs.
1927	28	10	0	23	3	2
1928	28	2	0	23	13	0
1929	35	1	0	24	15	0
1930	24	19	3			

Even on the average farm, however, there are some crops which can be made to give far higher increases than any of those shown in Tables II and III; and that not only on land in fairly good heart, but also on all except the very poorest soil. These are the so-called greedy crops, those which have an all but unappeasable hunger for nitrogen. The cabbage tribe, particularly the different kinds of kale, are greedy crops. Their large aptitudes for fertilizers are illustrated fully in Chapter X. The cabbage tribe represents one extreme of the range of capacity of plants to avail themselves of nitrogen. At the other end of the scale are the relatively abstemious crops, of which cereals, wheat, &c., are examples. The frugal appetite of the cereals is sooner satisfied. Whereas several successive applications of nitrogen fertilizer call forth increasing yields in the case of the greedy crop, the limit of increase is quickly reached in the more frugal crops.

Inasmuch as the greedy crops (kale, potatoes, bush fruit, &c.) respond so generously to fertilizers, it is safe to say that were they supplied more liberally with them, these crops would yield greatly in excess of the amounts allowed for in the estimates presently to be given.

This conclusion is also true, albeit to a lesser extent, of the nitrogen-thrifty cereals, wheat, barley, and oats. It is indeed to its frugal habit that the wheat plant owes its powers to produce some sort of a crop even on the poorest soil, and to this, in turn, wheat owes its ubiquity as a food plant. Although the nitrogen-frugal cereals can make no lavish use of nitrogen, yet they too must be adequately supplied with it and the other plant foods if they are to give good crops.

The farmer, however, is confronted with a dilemma: he

must either withhold nitrogen fertilizers from the corn crops, or must run the risk of the corn lodging, that is to say, falling down prone on the earth at any time from the shooting of the ear up till harvest. How this dilemma may be avoided is described on page 155; here it suffices to say that unless wheat receives in spring a dressing of nitrogen fertilizer, the average yield (17·7 cwt. per acre) will remain low. The Rothamsted and Jealott's Hill figures and the results obtained on the Recorded Farms show that, risk of lodging notwithstanding, both winter and spring-sown cereals should receive not only adequate supplies of phosphates and potash, but also a spring dressing of a nitrogen fertilizer.

Fertilizers and crop production in Germany and Holland. Larger examples than any yet given also prove that if increased food production is to be secured, the efforts must go hand in hand with an increased use of fertilizers.

Germany in the years after the War found herself with large supplies of nitrogenous fertilizers, and it is not surprising that she turned these materials to agricultural uses with as much energy as she had previously employed them for belligerent purposes. During the years 1925–30 the agricultural consumption of nitrogen fertilizer in Germany, compared with that of 1919–24, increased by 61 per cent. As Table VII shows, increased yields of all farm crops went hand in hand with the larger use of fertilizers.

Holland provides a no less striking example of the great results which can be achieved by fertilizers. The quantities of the three plant foods which are added to the soil by Dutch farmers are compared in Table VIII with those which are used by British farmers. The comparison shows that acre for acre Holland uses nine times as much nitrogen

fertilizer, five times as much phosphate, and nearly twelve times as much potash. These figures, however, if taken at their face value, prove too much, and therefore before any conclusion can be drawn from them some account must be given of the difference of soil and of system of cultivation in the two countries.

Table VII

Nitrogenous Fertilizers and Yields of Crops in Germany during the periods 1919–24 (=100) and 1925–30

	1919–24	*1925–30*
Relative consumption of Nitrogen Fertilizer:	100	161·3
Wheat	100	115·7
Barley	,,	117·5
Oats	,,	118·4
Rye	,,	107·9
Potatoes	,,	118·6
Sugar beet	,,	112·6

Table VIII

Comparison of Fertilizer Consumption (Great Britain and Holland)

	Great Britain *1928–9*		Holland *1929*	
	tons	lb. per acre	tons	lb. per acre
Inorganic nitrogen	42,000	3·1	70,000	28·8
Phosphate (P_2O_5)	120,000	9·0	120,000	49·4
Potash (K_2O)	42,000	3·1	85,000	35·0

The Dutch farmer grows his arable crops mainly on light land well watered by canals; the arable crops in England are grown on both light and on heavy land. The light soils of Holland are generally deficient in potash; much, but by no means all, British arable land contains plenty. It would therefore be unsafe to rely on any

conclusion drawn from the figures relating to potash. The admirable system of canals in Holland, admirably managed, permits of the water-level in the soil being kept under control, and because of this the land can be maintained in a very high state of fertility by means of fertilizers alone. In Great Britain there is scarcely any district with waterways comparable with the canals of Holland, and, moreover, much of the arable land is heavy. In these circumstances the British farmer must resort to laborious means for maintaining the fertility of the soil. One of these means is to use as much farmyard manure as he can get, although, in point of fact, the British farmer uses acre for acre over arable and grass land no more than the Dutch.

A second means employed by the British farmer to maintain the fertility of the soil is to sow arable land down to grass at regular intervals. The temporary grass, a mixture of grasses and clovers, is left in possession of the land for a year or longer. During this time the soil amasses humus, that is to say, organic matter rich in nitrogen. When the grass is ploughed up, the land, now ready for an arable crop, contains large stores of nitrogen in the form of humus. The humus decaying in the soil gives rise slowly to the selfsame plant foods which are contained in fertilizers. Therefore the amount of humus nitrogen must be brought into account. The quantity of nitrogen added to the arable soil of Great Britain by the decay of the humus of the ploughed-up ley may be put at 21 lb. per acre. The British farmer has, as it were, this amount of nitrogen to his credit. When this is allowed for (see Chart II) the figures of relative consumption of nitrogen from all sources—fertilizers, farmyard manure, and humus—are:

Holland	. . .	50 lb. nitrogen to the acre.
Great Britain	. . .	38·8 ,, ,,

Yet, as these figures show, even after making full allowance for the different systems of farming, the fact remains that the Dutch farmer supplies his crops with nearly

NITROGEN CONSUMPTION AND CROP YIELDS

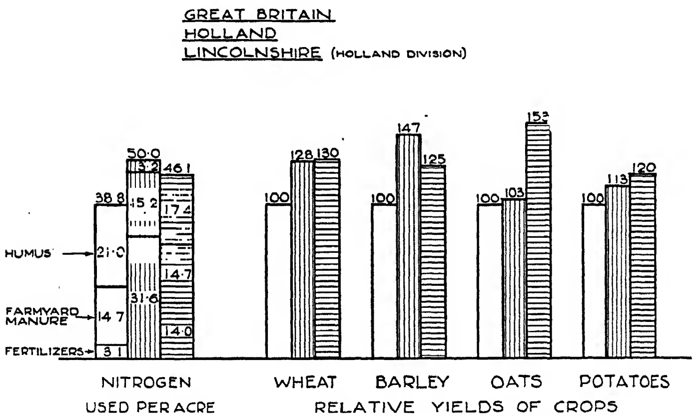

CHART II. Nitrogen Consumption and Crop Yields.

25 per cent. more nitrogen than does the British farmer. No wonder his crops are 25 per cent. bigger!

Phosphates tell the same tale and point the same moral, for it cannot be said with respect to this fertilizer as it can be of potash, that the soils of Great Britain often contain a sufficiency of this indispensable plant food. They do not. Therefore it must be conceded that the larger use of nitrogen and phosphates by the Dutch farmer constitutes the main reason why his yields are superior to those of this country.

High farming in the Holland Division of Lincolnshire. It is possible to check this conclusion by an example which shows that there are districts of this country which equal, if they do not surpass, the productivity of Holland. The Holland Division of Lincolnshire, with an arable acreage of 189,462 (1930), is a region of high farming. As the name suggests, it enjoys conditions which, though rare in this country, are very similar to those of Holland. Canals intersect the arable fields, and the level of the canal water is under control.

The farmers of the Holland Division use on the average more than four times the amount of nitrogen fertilizer used by the average farmer of Great Britain (see Chart II). The total amount of nitrogen from the three sources already mentioned used in the Division is about the same as, or only slightly less than, that used in Holland:

Holland Division . .	46·1 lb. nitrogen per acre.
Holland	50 ,, ,,

It is as gratifying as it is surprising therefore to discover from Chart II that the farmers of this favoured part of England equal, if they do not excel Dutch farmers in their power of raising large crops from the land.

All these examples taken together prove beyond a peradventure that crop production increases with the increased use of nitrogen and other fertilizers, and that the land of Great Britain in its present state, hungering as it is for plant foods, is by no means producing to the full extent of its capacity.

What of the grass lands of Great Britain: can they add their quota of increase?

IV

FERTILIZERS AND GRASS LAND

Productivity of grass land. Great Britain a grass-land country. Grass a complete food for stock. The successional cropping of grass. Comparative yields of arable and pasture. Early bite. Effects of over-grazing early grass. Recovery from drought. Levelling up grass production. Nitrogen and:—increased yield, hay production, quality of grass.

IT was shown in the preceding chapter that large powers of increased food production lie latent in the arable land of Great Britain and that these powers become active when deficiencies of the essential plant foods in the soil are made good.

It has now to be shown that similar and yet larger powers lie latent in grass land, and that similar means may be used to call them forth.

Great as is the capacity of arable land to produce more food, that of grass land is far greater.

The productivity of grass land. In the first place there is more of it. The acreage of land in Great Britain and Northern Ireland which in any year is bearing arable crops is 10,101,000 (see Table C, Appendix I). All the remainder of the agricultural acreage is grass land.

Permanent grass occupies	17,996,000	acres.
Temporary ,, ,,	4,638,000	,,
Rough grazings occupy	15,338,000	,,

or, if the rough grazings are left out of account, the areas are:

Land under arable crops	10,101,000	acres.
,, ,, grass	22,634,000	,,

In the second place, the capacity of grass land to give

increased yields when properly managed and sufficiently fed exceeds that of arable land.

The great potentialities of grass land for food production have only been discovered in recent years. They are not yet generally known, and are only just beginning to be exploited on the farm.

It is therefore of special importance that the hitherto unsuspected powers of pasture land to increase food supplies should be fully described and proved.

Great Britain a grass-land country. Great Britain is pre-eminently a grass-land country. It has been endowed by Nature with a climate in which grasses and clovers thrive. Except in the drier eastern counties of England, the rainfall is high enough and well enough distributed over the grazing season of the year to produce luxuriant crops of grass; and the only adverse conditions against which pasture plants have to contend are drought and shortage of food.

Grass is the natural vegetation of by far the larger part of the land. An arable field left uncultivated tumbles down to grass; in the course of a few years it becomes more or less covered with grasses, clovers, and their attendant weeds. In many districts these natural pastures supply fair grazing for sheep and cattle. They may be made to do so in all.

The mildness of the climate generally, as well as its humidity, encourages the growth of grasses throughout many months of the year, and when grass land is not starved of nitrogen and mineral foods, as for the most part it now is, the period of growth becomes yet longer.

Spring and summer drought, though often more harmful to pasture than to arable crops, is by no means a fatal enemy. Though it may scotch, drought rarely kills grass.

When rain comes, the parched grass renews its growth with a vigour shown by few, if any, other kinds of plant. Grass is hardy. Winter frost may sere the leaves. They turn brown and wither, but frost rarely kills the plant. Grasses will flourish under conditions of wetness of soil fatal to most arable crops.

The almost incredible powers of food production possessed by pasture land are due chiefly to three causes. One lies in the habit of growth of grass; another in the high feeding value of its leaves, and a third in the successive growth throughout spring, summer, and autumn made by the different plants which constitute a pasture.

The form and habit of a pasture grass are the outcome of age-long interaction between grass and grazing animal. The stems and the buds which the stems bear lie prone on or beneath the ground. They are safe. Each of the buds of the growing grass plant sends up leaves one at a time. If the first leaves are bitten off, another set of leaves and yet others follow regularly throughout spring and early summer. When all the leaves which a bud can produce have been eaten down, there are plenty more to succeed them; for in the meantime the prostrate stem has produced yet more leaf-forming buds. Only if the grazing is excessive in the early part of the year, or if a spell of drought occurs, is there a check to the constant renewal of leafy growth until the time comes for the grass to flower. Even then the year's work is not finished. After a brief period of rest, grass begins to grow again, throws up fresh crops of leaves, and continues to do so until winter comes.

The clovers also possess prostrate stems running along the surface of the ground, and they also offer up their young leaves in succession to the grazing animal, so that

of both grass and clover it is, within wide limits, true that the more they're bitten the better they be!

Grass a complete food for stock. The second cause which makes grass a prolific producer of food is the richness of its *young* leaves in the food substances essential to the life and growth of animals. Each young leaf is a closely packed storehouse of nitrogenous food (proteins), sugars, and other carbohydrates, and also of those mineral substances which are no less essential to animal nutrition. Recent and as yet unpublished experiments made by Professors J. C. Drummond and I. M. Heilbron and Dr. R. A. Morton, in co-operation with Jealott's Hill, show that the young leaves of grass and clover are rich in food of another and no less important kind. They contain carotene. This substance when it passes into the body of a grazing animal—a cow for example—gives rise to vitamin A, the vitamin which encourages growth in human beings as well as animals, and confers on them powers of resistance to disease. The milk which the cow gives contains the vitamin as does also the butter made from the milk, and so in this way grass helps to rear a healthy people.

Young grass is, in fact, a highly nutritious, digestible, and wholesome food for stock. Although the balance between its proteins and carbohydrates is not perfect, grazing trials show that dairy stock fed on grass alone maintain weight and give high milk yields.

Some foods have a preponderance of one kind of material. Maize meal, for example, is mainly a starchy food. Used alone it will not long maintain the life and health of a growing animal. Maize meal must therefore be mixed with other foods which supply enough of those nutritive materials which it lacks.

Hay, though less incomplete than maize, is not a complete food from the dairy farmer's point of view. It will keep a cow alive and in good health, and will enable her to produce up to a gallon and a half of milk a day. More than that hay—at all events hay of average quality—cannot do, no matter how much of it is fed to the animal. If she is to give a full yield, the cow must have a supplementary ration of some other kind of food rich in the nitrogenous food substances in which hay is relatively poor. For this reason when cows come off the pastures in late autumn and are put on winter rations, they get hay for maintenance and a concentrated food to enable them to keep up the milk yields.

Grass, on the other hand, is a complete food for dairy stock, as well as for other grazing animals. Its chemical composition, given in detail in Appendix V and in summary in Table IX, shows that it contains all the essential food substances, and contains them in suitable proportions:

TABLE IX

The Nutrient and Mineral Contents of Intensively Manured and Rotationally Grazed Grass

(*Stated on the basis of the Dry Matter*)

Starch value*	62·0
Protein equivalent†	15·0
Lime (CaO)	0·82 per cent.
Phosphoric acid (P_2O_5)	0·75 per cent.

* The starch value 62 means that 100 lb. of the foodstuff—grass—provides the animal with as much energy, or material for storage as fat, as is provided by 62 lb. of pure starch.

† The protein equivalent 15 means that 100 lb. of the food material—grass—supplies to the animal nitrogenous food equal in amount to that contained in 15 lb. of pure digestible protein.

starchy and nitrogenous food and the essential minerals, phosphates and lime; all in adequate amounts.

Feeding trials confirm this conclusion. They prove that a diet of grass alone suffices to keep cows in health, enables them to maintain or increase their body-weight, and to yield up to six gallons of milk a day (p. 65).

The successional cropping of grass. The third cause which makes pastures prolific lies in the fact that they do for themselves what good arable farmers would so much like to do: grow a succession of crops in one and the same season. First to appear with spring time is rye grass. Its productivity in a well-managed pasture continues until June. Then the rye grass flowers or tries to; after which it takes a short rest. Next to appear is cocksfoot. It begins a few weeks later than rye grass, and runs a similar course. Following cocksfoot comes rough-stalked meadow grass, and then that regular summer crop, wild white clover, which gives grazing in July and August, just when the grasses are at their lowest ebb of growth.

In the meantime, however, the earliest grasses have begun to grow actively again. They go on growing, unless their food supplies give out, all through the autumn and even into winter. Only when falling soil temperature and frosty nights put a veto on growth do they bring the year's work to a close.

Comparative yields of arable and pasture. It would be natural to suppose after this recital of the aptitudes for crop production possessed by pasture plants that the yields from grass land are higher than those of arable crops: that the hay from the meadow or the grass of a pasture contains more food than cereals or other crops grown on a similar acreage. A comparison of the yields of arable and

grass land shows that the expectation is erroneous, and that the food-producing powers of arable land are greater

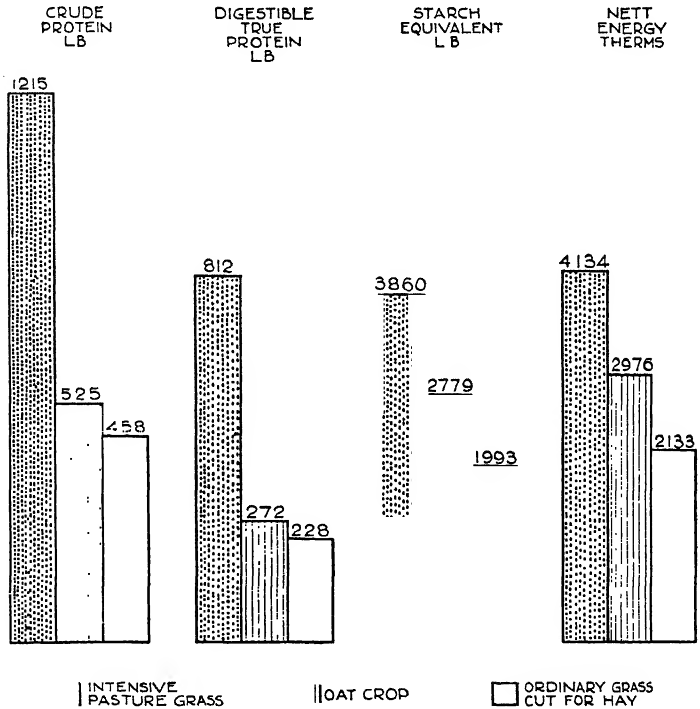

CHART III. Relative Feeding Values of Arable and Grass-land Crops. Oats, Ordinary Grass, Intensive (Nitrogen-Treated) Grass.

than those of grass land. A good crop of oats yields 26 cwt. grain and 50 cwt. straw per acre. An acre of good grass land produces 200 cwt. of grass or 40 cwt. of hay.

The comparative food values of oats and grass are shown in Chart III. Whether measured in terms of nitrogenous

food substances (proteins) or whether all the food is reckoned as starch, or in terms of its energy-producing power, the oat crop proves itself easily and in all respects superior to the grass crop.

Grass land as it is, is the inferior of arable land as a producer of food.

No wonder, therefore, that farmers generally have devoted their attention more to arable crops than to grass land, and that the most that grass land gets as a rule is, it may be, a dressing of dung, and a periodical application of basic slag or other phosphatic fertilizer, together with an occasional harrowing and a rolling in spring.

Yet all that the figures of food values of the grass and oat crops tell is that a crop half-starved is inferior to another fairly well fed. When the need of grass land for food is satisfied, the tale is a very different one. Inherent capacities so long latent become active, and grass land shows its true powers. It becomes transformed: instead of producing less than the oat crop, it yields acre for acre, much more. As Chart III shows, grass supplied plentifully with nitrogen and mineral food yields more than double the amount of crude protein, nearly treble the digestible protein, about a third more total food measured as starch, and stores of energy one-third more than are contained in the oat crop.

Grass land is now seen to be not the inferior but the superior of arable land in capacity for food production. When its reserves of power at present unused are called up for active service, food production will receive the most powerful reinforcement which it is possible for it to get. Knowledge of the fecundity of grass land makes rapid headway. It is beginning to be applied by many farmers

in this country, but nowhere is it being put into practice more vigorously than in New Zealand, where, thanks to the pioneering work of Messrs. R. L. Robb and W. V. Blewett, and Dr. H. E. Annett, and to the enterprise of the New Zealand Department of Agriculture, there are already 3,000 farmers—expert graziers all of them—who are applying nitrogen and phosphatic fertilizers to their grass land.

Unlike arable land, which, except in rare cases, produces a single crop in the year, grass land can be made to exercise all those powers of successional cropping which are inherent in it, and when this is done it will provide the most important of all means of increasing supplies of home-grown food.

Early bite. The earliest attempts in this country to apply to grass land new principles of management combined with liberal feeding by means of fertilizers were made in 1926. They led immediately to a new discovery of great practical importance: the precociousness of the growth which grass makes when its food requirements are satisfied.

Nitrogen brings spring earlier to the pastures. The fact that this is so was discovered in the course of experiments on the use of fertilizers on grass land. Pastures were dressed with mineral fertilizers in the autumn or winter and with nitrogen in the early months of the year. The result was that when the nitrogen was put on so early as February or March grass came earlier than it did in the pastures which received no nitrogen. This fact, now well established, was the starting-point for the efforts now being made to induce farmers to take steps to secure an early bite on all suitable grass land throughout the country. Wisdom after the event supplies a simple and possibly correct explanation of the earliness induced by nitrogen.

The grasses of a pasture start growing in spring when the soil has become warm enough and when they can get from it the nitrogen and mineral plant foods which they need in order to make new leaves, stems, and roots. Unless both warmth and food are there, no growth takes place. In natural pastures growth has to wait until both these conditions have been fulfilled. The ground is warm enough, but the supplies of plant food in the soil are not ready. They, and particularly nitrogenous food, are slow in getting themselves mobilized. Until they are mobilized by natural processes, grass goes on waiting. But if nitrogen food be given, it begins at once to grow vigorously.

That lack of nitrogen plant food leads to backward growth on pasture land in spring is a fact that has been amply proved by many hundreds of experiments.

An example of the results of one of the numerous experiments on early bite is to be seen in Chart IV. Two sets of eight plots each of equal size were set aside for the grazing of sheep in the spring of 1930. One series received mineral fertilizers only, the other had nitrogen as well. The grass on the plots which got no nitrogen had made but little if any growth by April 29th, and until May 13th very little grazing was to be had from them. On the nitrogen plots, on the other hand, there was already plenty of grass by April 15th, and, as the chart shows, they had yielded by May 13th seven times as much grazing as the no nitrogen plots.

Another no less striking and similar result was obtained in the following year. Grass on the nitrogen plots reached a height of 4 inches and was ready for grazing on April 1st. The plots which had been left alone lagged behind and were not ready until April 16th.

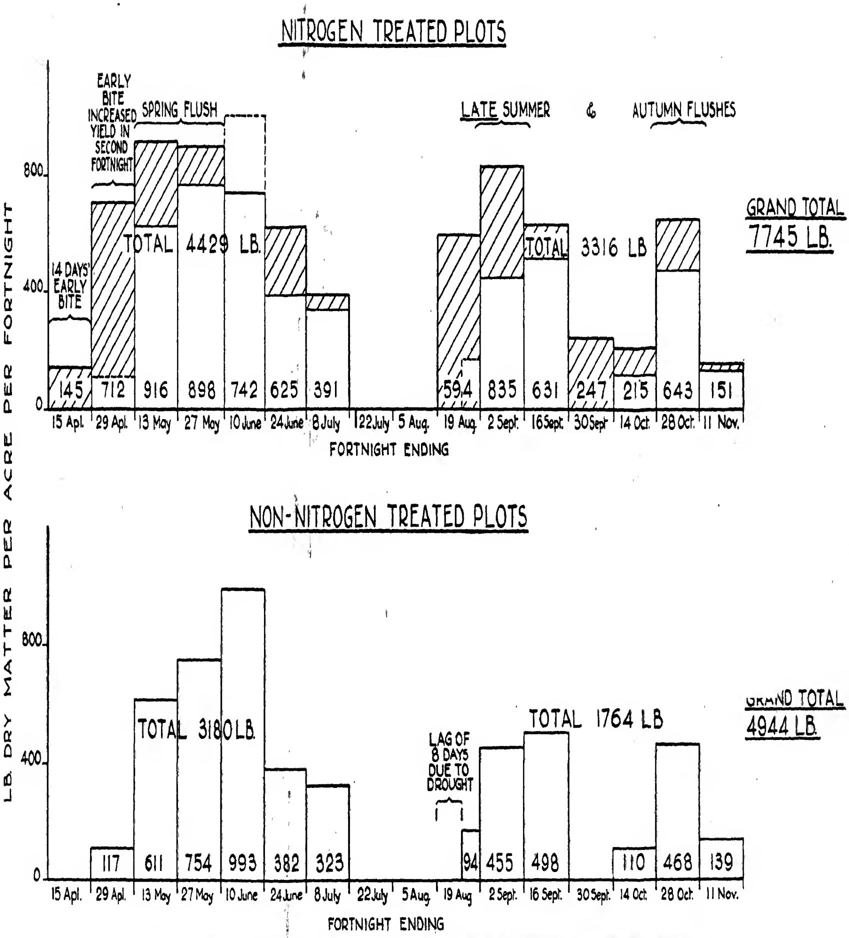

Chart IV. Effects of Fertilizers on Earliness, Drought Resistance, Yield, and Steadiness of Production of Grass Land.

Two years before the latter experiment was made the evidence that nitrogen produces an early bite was already so conclusive that steps were taken to show farmers how to get early grass. Early bite trials, numbering 492, were made in different parts of the country in the years 1929 and 1930. In each trial, demonstration fields, or parts of fields, were treated in spring with a nitrogen fertilizer, and the earliness of the nitrogen plots was compared with that of plots which received no nitrogen. In 447 cases (91 per cent.) the grass was ready for grazing from 14 to 28 days earlier on the nitrogen plots than it was on the plots left in their natural state.

The dressing which was generally employed in these experiments was 1 cwt. nitrogen fertilizer per acre, and, as the results show, this amount proved effective. But it was also found in the course of the investigations that a double dressing of 2 cwt. had a marked effect in increasing yet further the yield of early grass.

It goes without saying that if an early bite is to be obtained, early grasses must be present in the pasture. Where this is the case and the sward contains a fair proportion of the early perennial rye grass, the response is great. Where rye grass occurs in smaller proportion, the earliness is less marked. Where there are no grasses capable of early growth, nitrogen cannot conjure them into existence, at all events in a single year, and there, as is inevitable, no early bite is obtained. For example, a very poor pasture in which the grasses known as bents predominate can give no early grass. The bents are late grasses. They respond to nitrogen by beginning to grow earlier than is their wont, but even so they are not ready by what should be the beginning of the grazing season.

The degree of response depends upon the condition of the grasses in the pasture. For example, at Jealott's Hill, where, for the purpose of an experiment of another kind, a plot had been cut seven times during the previous season but had not been stinted of plant food, perennial rye grass had not produced by April 1st more than one-quarter of the growth made on similar plots which contained the same grasses and had been treated in identical manner, except that they had been cut only twice in the year. Excessive cutting enfeebled the grass, so that it took longer to recover and resume growth in spring. It therefore follows that fields which are to be laid up for early bite should, if they are to give their best results, be so managed in the previous year that the grasses, and especially the early ones, have every chance of growing strongly.

It might be supposed that what at first sight looks like artificial forcing to get early growth would do harm to the pastures. It does not. It improves them. Nor is this surprising; for if the early grasses are not encouraged to grow by giving them a supply of the plant food which they lack, they become weak and are apt to be suppressed by other members of the grass community.

The appointed time for the growth of the early grasses is the early spring. If they are able to grow then they have the field very much to themselves. They flourish. But if these pioneers of spring pastures are not able to advance by reason of lack of supplies, when at last supplies are brought up by the slow natural mobilization of the nitrogen of soil the earliest grasses begin to grow, but now they find themselves in competition with the less early grasses. Those which should have succeeded them are now their rivals. Both suffer. In the natural world the

time of growth is out of joint and only nitrogen can set it right.

Effects of over-grazing early grass. It is a very general custom, especially in sheep districts, to over-graze grass in early spring. Grass is badly needed then, and so soon as there is any the grass lands are stocked heavily. The grass is eaten down as fast at it appears and, as a consequence, the pastures in course of time become deficient in early grasses. A vicious circle is drawn. Next year the grass is later still, and when it does appear it is again grazed heavily until the pasture becomes a later and later one.

The truth is that in spring all the grasses of a pasture are suffering from insufficiency of nitrogen. All respond to nitrogen. Those which are naturally early make the response first. Those which are not also respond, but they begin, as they need must, later than the early grasses.

Knowledge of the way to get an early bite is becoming general among farmers, and the area of pasture which is treated with nitrogen fertilizer in the spring is increasing year by year. The advantages to the farmer are clear; given suitable weather he can turn his live stock out a fortnight or more earlier, and, by letting them graze, save the cost of expensive concentrated foods with which otherwise he must feed them, and he can also put the labour required for the care of the indoor animals to other uses on the farm.

The advantages are even greater in the case of sheep. They are out in all weathers; the early spring is the season of lambing; and a plentiful supply of food means a good flush of milk in the ewes and a good early lamb.

The yield of early grass is large and, as is shown by the result of an experiment made in 1930, increases with

increasing amounts of nitrogen fertilizer. Compared with the yield of no-nitrogen grass

1 cwt. nitrogen fertilizer gave an increase of 14·5 cwt. fresh grass per acre.
1½ cwt. nitrogen fertilizer gave an increase of 17·6 cwt. fresh grass per acre.
3 cwt. nitrogen fertilizer gave an increase of 37 cwt. fresh grass per acre. (*All cut on May 5th.*)

It might be expected that a high yield in spring would lead to a slower growth subsequently. It does. But nevertheless the total yield throughout the season from nitrogen grass remains very much higher than the yield from no-nitrogen grass. The more vigorous early growth induced by nitrogen uses up much or all of the nitrogen supplied by the fertilizer. The pasture is once again hungry for nitrogen. A second dressing relieves the hunger. As a result the mid-season yield jumps up, overtopping that of the natural grass. So it is again later in the year after the second cut has been taken, or the second grazing done. A third dressing makes good the deficiency of nitrogen, and again there is a yield often double that produced by the natural grass, the under-production of which is due to lack of nitrogen food. Young grass, like the young child, is always hungry, and grows the better the oftener it is fed.

Recovery from drought. It is well known that grass ceases to grow in periods of drought. It is not, however, well known, nor indeed was it suspected until proved by experiment, that the rate of recovery of pasture land from drought depends on the presence of available nitrogen food in the soil. The nitrogen may be there, but locked up as it is, it is slow in getting to the plant. But when a quick-

acting nitrogen fertilizer is applied to the soil much of the nitrogen in it is ready for immediate use. It is another case of early bite over again.

There was a mid-summer drought in 1930, and a consequent shortage of grass lasting from July 7th to August 11th. During the dry spell and afterwards, nitrogen-treated plots and similar plots which had received no nitrogen fertilizer were kept under observation. The results are shown in Chart IV, facing p. 46. The nitrogen plots recovered quickly. Within twenty-nine days of the breaking of the drought they had produced plenty of grass and were being grazed. The no-nitrogen plots remained almost bare of grass until September 2nd, and indeed the late summer grass never recovered fully from the effects of drought. The no-nitrogen plots, as the chart shows, gave during August and September just about half the grazing provided by the nitrogen plots. Nor did the no-nitrogen plots make up in the autumn. Their yield was only three-quarters that of the nitrogen plots.

At the same time it would be wrong to minimize the seriousness of drought. A dry spell may be expected once every three years at least. The effects of drought can, however, be mitigated. The mixed farm can grow lucerne or other forage crops for use in dry periods. The grass-land farmer, taking advantage of the larger yields which nitrogen fertilizers give, can lay up stores of hay for use in droughty times or, as shown in a later chapter, he can convert some of the surplus grass into ensilage. With such reserves at his command drought ceases to be a disaster, and becomes only a costly nuisance.

Levelling up grass production. Records of yields from pasture land taken at intervals throughout the year show

in almost all parts of the world, and very strikingly in this country, how sporadic is the natural growth of grass in pastures. There is a slow start, a sudden, large, and brief flush of growth, reaching its peak at the end of May, and then a decline, complete in some districts, partial in others, lasting until mid-July. Where clovers are largely present in the pasture their growth compensates for the decline of the grasses. After a short rest the grasses, refreshed in vigour, make a second smaller flush of growth, which reaches its maximum in mid-September and fades with the year.

This natural rhythmic habit of growth is illustrated in Chart IV, facing p. 46, where it is compared with that of grass liberally supplied with nitrogen as well as the essential mineral plant foods. When phosphates and potash only are given, even though given liberally, grass still maintains its natural irregular rhythm of production. When nitrogen is also added, brief exuberance gives place to steadier growth. Grass keeps now a more even tenor of its way. The nitrogen grass begins earlier, the slowing down may take place at much the same time in nitrogen and no-nitrogen grass, but the former is the sooner to begin to grow again in the middle summer. August sees it up and doing, and again nitrogen grass goes on yielding liberally over a longer period, until winter sets a term to its activities.

The levelling up of production due to nitrogen is shown in the same Chart, in contrast with the irregularity in untreated pastures, and it will be evident to any one who uses pastures for grazing that the power of nitrogen to spread growth over a longer period is, in itself, of great advantage to the grazier. It helps him to overcome the

difficulty which he has to face when brief periods of plenty are followed by dearth, as is the case with natural pastures.

The sharp and high rising peak of natural production in the early part of the year, overtopping as it does the more constant level of production of the nitrogen grass, is in itself a nuisance. There are not enough animals to graze the grass. It has to be left alone—wasted and detrimental to the pasture—or else store cattle are bought in to eat down the surplus spring grass—and that at a time when Nature's bounty is tempting others to do likewise, with the result that the prices paid for the extra stock may prove to be more than they are worth. It is indeed, as many are beginning to realize, better for the farmer literally to cut his losses by running the mowing machine over the fields which are growing away so rapidly from the grazing animals.

Nitrogen and increased yield. Experiments carried out at Jealott's Hill and in all parts of Great Britain and Northern Ireland, in the Irish Free State, Canada, Australia, South Africa, and in New Zealand, by or under the auspices of the Research Staff, all show that the total yield of grass from nitrogen-treated pasture greatly exceeds that from pastures which have received no nitrogen.

The only qualifications which attach to this otherwise universal fact are, first, drought may be so severe as to stop all growth and, secondly, shortage of other plant food, whether it be phosphates, potash, or lime, may prevent nitrogen from doing its work.

The experiment already used to illustrate early bite, the recovery from drought, and the evening-up of production due to nitrogen, shows also the increases of total yield

brought about by this means. The yields, as shown in Chart IV, facing p. 46, are:

	Spring flush	*Late Summer and Autumn flush*	*Total lb. dry matter per acre*
Nitrogen grass . .	4,429	3,316	7,745
No-nitrogen grass. .	3,180	1,764	4,944

Measured as fresh grass, the nitrogen plots gave 18 tons as against 10½ tons from the no-nitrogen plots: an increase of 7½ tons to the acre, or 75 per cent.

These figures, striking as they are, do not reveal all the benefits which nitrogen confers on pasture. The nitrogenous food (protein) contained in young grass is the most valuable part of it. It is increased when adequate supplies of nitrogen are put at the disposal of the plant. It is increased in two different ways, as is shown in Chart V, p. 55. The crop is increased, and therefore since nitrogen grass does not contain less nitrogenous food than no-nitrogen grass, a proportion of the increase is due to the larger crop. In the present experiment the excess of nitrogen grass over no-nitrogen grass is 75 per cent.: therefore the amount of nitrogenous food contained in the former should be 75 per cent. more than in the latter. Analyses, however, showed the following results:

The nitrogen grass . .	246 lb.	protein per acre.
The no-nitrogen grass . .	122 lb.	,, ,,

that is to say, 100 per cent. increase. Therefore the additional 25 per cent. is due to the fact that pound for pound nitrogen grass contains more protein than does no-nitrogen grass.

The addition of the nitrogen fertilizer enables grass to make more leaves. It also improves the efficiency of the grass plant as a manufacturer of the nitrogenous food

required by stock and, as a consequence, every blade of nitrogen-treated grass comes to possess a higher feeding value.

The increase in yield brought about by nitrogen, though

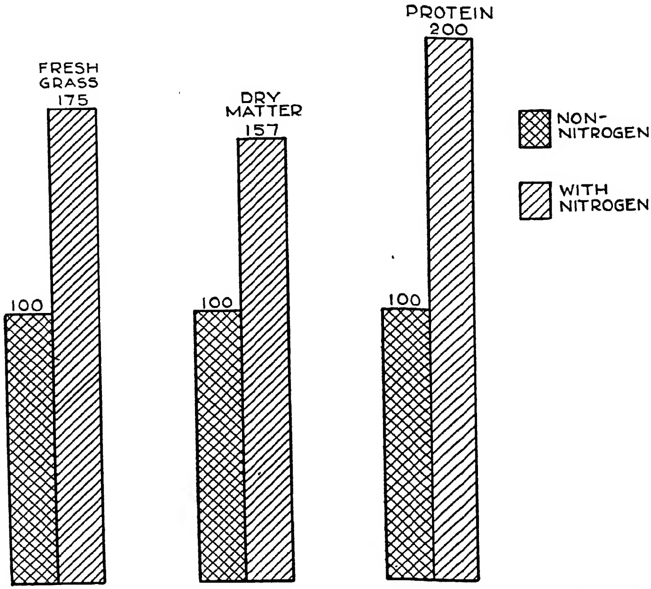

CHART V. Comparative Yields of Grass treated and not treated with Nitrogen.

always great, must, of course, vary with the composition of the pasture, the kinds of grasses which grow in it, and the weather experienced during the growing season. A pasture predominantly grassy and well supplied with the early grasses responds most. A pasture mainly composed of clovers responds least, for clovers make their own nitrogenous materials, synthesizing them from the nitrogen in

the air. Therefore, when nitrogen is applied to a predominantly clover pasture, little or no effect is produced until the grasses have had time to assert themselves and have come to occupy a fair part of the sward.

A dry season depresses yields, so that the difference between pastures which have been dressed with nitrogen and those which have not become less marked. For example, the experiment just described (p. 55), which showed such large increases, was begun in the previous year (1929), and in that year—a dry year—the difference in yields between the nitrogen and no-nitrogen pastures was less marked. There was only 40 per cent. more grass on the nitrogen-treated plots, but although total production is not so great, the value of grass produced in a dry year is far higher than that produced in ordinary years. A 40 per cent. increase in 1929, when grass was scarce, was even more valuable to the farmer than a 75 per cent. increase in the subsequent year, when grass was plentiful.

It has already been shown that the yields which nitrogen calls forth increase progressively with the quantity of nitrogen used to produce them. Where the limit of increase lies has not yet been determined, but in experiments carried out by Mr. G. E. Blackman the richest grass which it has been possible to grow by using extremely large quantities of nitrogen fertilizer was found to contain no less than 39·6 per cent. of crude protein, that is to say, double that of ordinary grass. The astonishing amount of nitrogenous food which grass can manufacture, although of great scientific interest and possibly of practical use in the future, is, for obvious economic reasons, of no immediate practical importance. The facts are, however, of

great value in showing how much there is still to learn about the food-producing capacities of grass-land plants.

Nitrogen and hay production. Meadow land responds to nitrogen no less than does pasture, but although farmers are aware of the fact and not infrequently apply nitrogen fertilizers to meadows from which a hay crop is to be taken, the practice is not so general, nor is the amount supplied so great as it should be.

The Jealott's Hill records (see Table X) show that 1 cwt. nitrogen fertilizer produced 50 cwt. of hay to the acre: 12½ cwt. more than from no-nitrogen plots. A double dressing produced nearly 58 cwt.: a ton more than was got from the no-nitrogen plots. A treble dressing yielded 68½ cwt.: 1½ tons more.

The heaviness of the trebly dressed crop led to a serious depression of the clovers, which, in turn, resulted in a smaller aftermath than that from the no-nitrogen grass; an illustration of the well-known fact that the more luxuriant the growth of the hay crop, the weaker the clovers become. The dressing of 1 cwt. nitrogen fertilizer had very little effect on the clovers; the aftermath was scarcely less than that from the control plot.

The depression of the clovers, although it may depress the farmers also, is of no importance. The clovers can be easily restored to their former vigour (see p. 118).

If a large yield of hay is required, a heavy dressing of nitrogen must be given, but if a large aftermath is wanted, either some hay must be sacrificed by the nitrogen dressing being made a lighter one or a second dressing of nitrogen must be applied after the hay been cut.

Knowledge of the high yield of hay obtained by means of nitrogen can be applied to the seeds leys: the temporary

grass. Where it is customary to sow down mixtures containing a good percentage of grasses, the seeds leys can be made to produce far more hay than they do at present. Where, however, clovers only are sown this method will produce no increase.

TABLE X

Yields of First Year's Seeds Hay 1930

	Nitrogenous fertilizer: cwt. per acre			
	0	*1*	*2*	*3*
Hay* . . .	37·6	50·0	57·9	68·5
Aftermath* .	24·8	23·0	21·0	17·8
Total* . .	62·4	73·0	78·9	86·3

* Dry weight at 65° C.

The power of nitrogen not only to increase but also to control production of grass was shown by the same field in the year following the experiment already described. In that year, 1931, of equal areas of the field of seeds hay, one received no nitrogen; another received 1 cwt. to the acre; a third, two successive dressings, each of 1 cwt., and the fourth, three successive dressings, each of the same amount.

The once dressed area gave a heavy first cut, but the second and third cuts showed a falling off as compared with the no-nitrogen yield. The twice dressed area gave a heavy first crop and a heavy second crop, but the third cut, taken in November, showed again a falling off. The thrice dressed area gave heavy first, second, and third cuts (see Table XI).

Natural grass in its very young stage is as good, or nearly as good, as nitrogen-treated grass, but there is far more of the latter. The work which an animal does in feeding itself is lightened if it can eat two blades of grass while it ate one before. A milch cow is both greedy and fastidious. When

TABLE XI

Second Year's Seeds Hay

Yields in Weights of Dry Matter* per acre.

	1st Cut June 16	*2nd Cut August 12*	*3rd Cut November 27*
I. No nitrogen fertilizer . .	17·66	4·79	5·62
II. 1 dressing of nitrogen fertilizer. 1 cwt. per acre in spring .	*24·97*	4·59	4·27
II. 2 equal dressings of nitrogen fertilizer. . . . . . 1 cwt. per acre in spring . 1 cwt. per acre after 1st cut .	*25·33*	*9·19*	4·93
III. 3 equal dressings of nitrogen fertilizer. . . . . . 1 cwt. per acre in spring . 1 cwt. per acre after 1st cut . 1 cwt. per acre after 2nd cut.	*25·84*	*9·99*	*9·54*

* Dry weight at 65° C.

it can, it chooses good things to eat and it always eats a lot. Cows love above all the first clip of young grass. Nitrogen-treated grass supplies a diet at once copious and delicate.

Quality of grass. The superior quality of nitrogen-treated grass shows itself not only in the animals' predilection for it, but also in its health-giving properties. The researches of Professors Heilbron and Drummond and Dr. Morton, referred to on p. 40, show that the amount of carotene, the forerunner of vitamin A, runs parallel with the amount of nitrogen contained in grass. It therefore follows from the figures already given, that an acre of nitrogen-grass contains twice as much of this precious natural medicine as does an acre of no-nitrogen grass.

Left to itself grass goes on leading, year after year, a

penurious existence. Save only on those rare pastures which seem to be supplied with everything that it can need, grass in a state of nature has to put up with a permanent shortage of both phosphates and nitrogen, and only too often insufficiency of potash and lime as well.

Nitrogen is the fuel which makes plant growth burn with a larger and steadier flame, but its force is soon spent unless it be aided by phosphates and potash; all three co-workers in the task of increasing fertility. They do this work hand in hand, and phosphates and nitrogen at all events go together into the plant. Dr. A. W. Greenhill has shown at Jealott's Hill that for every modicum of nitrogen which the grass plant takes up from the soil it takes up also a modicum of phosphates.

The large production induced by fertilizers means a large uptake of all the plant foods, and therefore if fertility is to be maintained they, the sources of fertility, must be renewed year by year, otherwise grass land returns again to the impoverished state in which it was before fertilizers came to its aid and made it strong and lusty.

The valuable investigations of Dr. J. Orr, Director of the Rowett Research Institute, have shown that minerals, including phosphates, may be used directly to give first aid to animals which are ailing, because they cannot get from the grass they graze the phosphates and other minerals which they need. There are parts of the world where this discovery is proving a boon to grass-land farmers, but in this country in all but the starveling grazings of the hills the indirect method of feeding the animals through the grass is likely to prove a better way of supplying mineral deficiencies.

So far as nitrogen is concerned, the present widespread

and large use of concentrated foods for feeding farm animals is a tacit recognition of the nitrogen deficiencies of natural herbage. The heavy bill which the nation pays for feeding stuffs will show a large reduction when grass is allowed to do all that it can do to yield the nitrogenous foods which at present have to be supplied in concentrated feeding stuffs.

Nitrogen and mineral plant foods make grass land earlier, more resistant to drought, lengthen seasonal production, and convert the natural periodic exuberance into steadier growth. They increase the quality of grass as well as the quantity and add to its health-giving properties. They give strength to the better grasses, encourage them to drive out the poorer, and so lead to permanent improvement of the grass land itself.

V

LARGE-SCALE EXPERIMENTS ON GRASS LAND

FARM EXPERIMENTS

Intensive grass-land management at Tollesby Farm. Production of summer milk without concentrates. Intensive grazing on 120 farms.

SMALL HOLDING EXPERIMENTS

The Jealott's Hill small holding. Small holdings in England, Scotland, and Wales. Irish small holdings.

FARM EXPERIMENTS

THE claim made at the beginning of the last chapter that the potentialities of grass land for increasing food production are even greater than those of arable land has now been substantiated.

Experiments in the intensive management of grass land were begun in this country in 1926 and have been continued ever since. They have demonstrated that rotational grazing of pastures fully supplied with nitrogen and mineral foods is capable of practical application. During these years knowledge of the food-producing powers of grass land was constantly growing, but it could not be said at any moment to be complete. It was, and is, nevertheless essential to get this important method of increasing the productivity of pastures tested out on a large scale and over a wide area.

Farmers and small holders were therefore invited to help to establish the new practice on a firm basis. There were fortunately many among them who were prepared to co-operate by putting the methods of intensive management of grass land to practical test on farms and holdings.

This chapter is the farmers' and small holders' contribu-

tion. It records the results of their efforts to apply new knowledge to the old and perennial problem—how to increase both production and profit from the grass land of the farm.

In all the experiments now to be described rotational grazing was practised on the lines which are laid down in Chapter VIII. The essentials are, first, that a continuous, successional supply of young grass is ensured by the use of mineral fertilizers, together with successive dressings of nitrogen, and, second, the adjustment of the number of grazing animals in relation to the area grazed so that grass is never left to grow tall or old and at the same time none is grazed to the bone. The grazing of the grass is controlled by dividing the grazing area to be put under intensive cultivation into a series of fields of approximately equal size and by causing the animals to graze the fields in turn and so soon as the young grass is ready for them.

Intensive grass-land management at Tollesby Farm. Mr. T. H. J. Carroll, who was the first to introduce to this country the system of intensive grass-land management which was beginning already to make headway in Germany, was fortunate in finding in Mr. W. Brunton a pioneer with the enterprise necessary to start something new.

Mr. Brunton, who has a dairy farm at Tollesby, near Middlesbrough, began the demonstration of intensive grass-land management in the spring of 1926. What was originally a demonstration is now an essential and profitable part of his farm routine.

Mr. Brunton has shown that good management must go hand in hand with liberal plant feeding. His experience enabled him to apply the principles underlying intensive management in the manner best suited to the conditions

under which he farms. For example, he is careful to make the transition from indoor winter to outdoor conditions a gradual one. During the first week after the cows are turned out they remain on the pasture only for a few hours each day. The grass grazed during this time provides daily food sufficient for one gallon of milk per cow. A sudden and complete change of diet is known to be as bad for animals as it often is for human beings, and trouble generally arises if precautions to prevent it are not taken. Some hay and concentrates are supplied for a week or more during the transition from indoor to outdoor conditions. There is plenty of grass for the animals to eat, but Mr. Brunton very wisely refuses the temptation of the pocket to cut off suddenly the supply of hay and concentrates to which the cows have been accustomed all through the winter months.

After two or three weeks the grass is allowed to supply a larger ration. The animals now graze throughout the day and get enough grass to supply maintenance and four gallons of milk per cow. A four-gallon cow is now feeding on grass alone. Higher yielding cows receive a performance ration for every gallon over four which they produce.

This routine is continued until the third week of August, when, lest the grass should be decreasing in nutritive value, Mr. Brunton begins gradually to feed an increasing amount of concentrated foods to the cows. By the end of August the grass provides three gallons of milk, in September two gallons, and in October, until the cows go into their winter quarters, one gallon of milk per cow.

The result of his careful management is that during the six years, wet or dry, in which he has practised intensive grazing he has maintained milk yields whilst reducing

the grazing area: four cows are carried to every three acres for a grazing period of 194 days and the grass gives in addition early grazing for sheep. Now and again the pastures yield so much grass that he is able to shut up one of the fields for a few weeks and take a crop of hay from it.

Production of summer milk without concentrates. The experimental farm at Jealott's Hill has also played its part in helping to apply the intensive management of grass land on a large scale.

One of the most important practical problems which it is helping to solve is the extent to which high-yielding cows can be maintained on grass alone. The importance of the problem lies in the fact that dairy farmers who sell milk must use every means in their power to maintain a steady yield. They have contracts to fulfil and, expense notwithstanding, they must deliver daily the amount of milk for which they have contracted. Their practice, therefore, is to supplement grass by a ration of concentrated food. They go farther than Mr. Brunton has found it necessary to go and generally feed concentrates for every gallon over three produced by a cow. The practice is expensive. Is it necessary? It was to supply an answer to this question that the experiment was made.

It was carried out in 1930 by Dr. S. J. Watson, in the following way. There were two groups of four cows each: the cows had calved shortly before the experiment began and their yields at the commencement were:

1	pair	of cows	each giving	6	gallons	per day.
1	„	„	„	5	„	„
1	„	„	„	4	„	„
1	„	„	„	3½	„	„

The cows of the two groups grazed together. The grazing area was divided up into six paddocks, which were grazed successively. The cows had the first bite and as they moved on the pasture which they left was grazed down by store cattle. The pasture was well supplied with phosphates and potash and received three dressings of nitrogen fertilizer in the course of the year.

The cows of one group, the 'concentrate' group, were fed according to the general practice. Each received an allowance of concentrated food for every gallon of milk in excess of three that she produced. The ration was given from May 4th, the date on which the experiment started, until August 6th. From then until November 2nd, when the experiment was brought to an end, concentrated food was fed to the 'concentrate' group for every gallon over two that a cow produced. The total amount of concentrates used throughout the season for this group of cows was 23 cwt.: $5\frac{3}{4}$ cwt. per cow.

The 'no-concentrate' group received no concentrated food whatsoever. They were fed on grass alone, save for three weeks of drought in July. During the drought both the 'concentrate' group and the 'no-concentrate' group had a ration of ensilage to make up for the shortage of grass.

The increase in live weight was the same in both groups. The yields (see Chart VI) were:

'Concentrate' group = 2,258 gallons.
'No-concentrate' group = 2,244 ,,

The yield per cow was, as near as may be, identical in the two groups: 564 gallons in the 'concentrate' group: 561 gallons in the 'no-concentrate'. Nor was there any difference in the composition of the milk produced by the

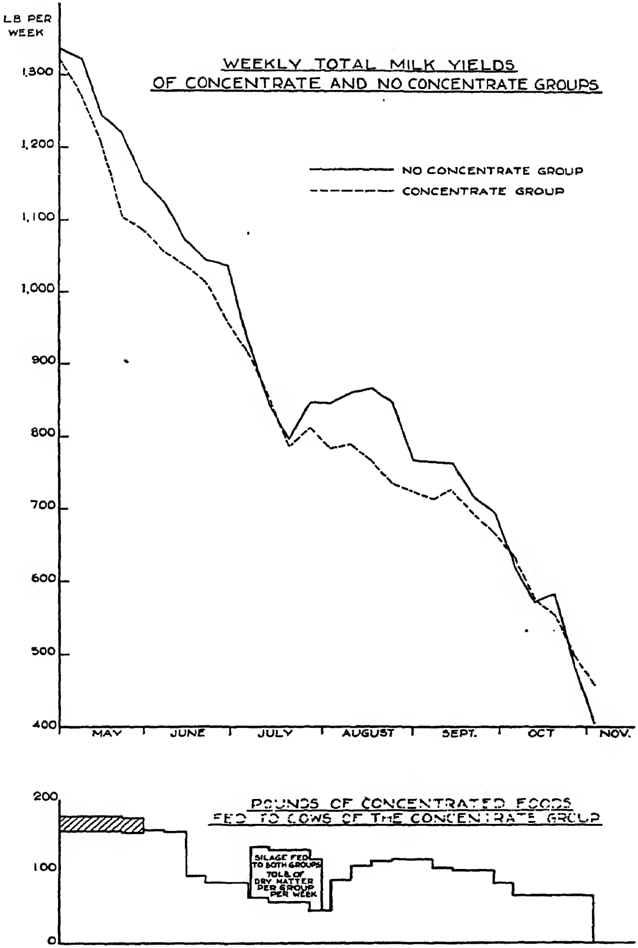

CHART VI. Comparative Milk Yields from Cows on Intensive Grass fed with and without Concentrated Food.

cows of the two groups; up till October the 'no-concentrate' group gave milk as rich in fats, nitrogenous substances, and total solids as the milk from the 'concentrate' group. Only in October, when the grazing season was approaching its end, did the 'concentrate' group show superiority in this respect. During the season yields of both 'concentrate' and 'no-concentrate' groups fell off at similar rates and in the normal manner shown by cows approaching the end of lactation. The chart indicates how closely the yields of each group run parallel with one another. The drop in yield seen in the 'no-concentrate' group in October shows also that—at all events at Jealott's Hill—grass, even though well supplied with plant food, decreases in nutritive value with the decline of the grazing year.

These results are confirmed by eight other similar experiments carried out in the same year by farmers. They all prove that grass plentifully supplied with the plant foods which it requires maintains the milk yield right up to the latter end of the grazing season.

There are not a few farmers who use grass in this way—to the full extent of its milk-producing capacity—but it is nevertheless true that the majority of dairy farmers use far more concentrated food than is necessary. It will undoubtedly become the general practice to supply milch cows with the nitrogen which they require for milk production, not by feeding nitrogenous substances directly to them by means of concentrated foods, but by giving the cheaper form of nitrogen in the shape of a fertilizer and leaving the grass to do the building up of the essential nitrogenous materials required for the feeding not only of dairy cows but also of sheep and cattle generally.

There is still more to learn from a continuation of this experiment, and only an outbreak of foot-and-mouth disease in the neighbourhood of the farm prevented it from being continued in 1931, with the object of discovering whether cows newly calved, say, in July or August, whose milk yields are *increasing* daily, can also be caused to continue their progressively rising yield when fed on nitrogen-treated grass without concentrates.

Intensive grazing on 120 farms. From one to two hundred farmers have co-operated during the past six years in carrying out grazing trials of a kind similar to that of Mr. Brunton. The farms on which the trials were made were chiefly dairy farms, but store stock and some sheep were also used for the grazing of the pastures. The results obtained in the year 1928, when the largest area was under experiment, are given in Table XII. In that year the number of trials was 120. The area under experiments was 2,740 acres.

The trials were carried out in England, Scotland, Wales, Northern Ireland, and in the Irish Free State. Included in the Free State trials are those made by arrangement with the Department of Agriculture. For permission to include the results of the Free State trials thanks are due to the Department of Agriculture, and acknowledgement is also due to the Agricultural Instructors under whose skilled supervision most of the trials were carried out.

The summary of the results of all the trials given in Table XII shows that there is a close agreement with respect to the area required for the grazing of one cow. It amounts on the average to nine-tenths of an acre, which, in itself, is a proof of the increased feeding value of grass when all its food requirements are satisfied.

TABLE XII

Carrying Capacity and Duration of Grazing Season on Intensively Managed Grass Land in the British Isles.

1928.

	England and Wales	*Scotland*	*Ireland*
Number of trials	59	25	46
Acres under experiment	1169	613	958
Acres required for the grazing of a cow	0·92	0·83	0·89
Grazing period, days	185	171	191

One cow to the acre or rather less is the more remarkable in that the farms on which the trials were carried out differed greatly in natural fertility. Some had good grass, some fair, and some poor, and the results of the trial show that even poor grass responds to proper treatment.

The period of grazing ranged from 171 days in Scotland to 191 days in Ireland.

Some of the districts in which the trials were made, as for example the hilly north-west of England, have a short grazing season. Other districts more favoured by climate, particularly those in Southern Ireland, have a much longer one. But, although it is difficult to estimate the length of an average grazing season, it may be put at something between 20 and 22 weeks, say 150 days. On this basis fertilizers had the effect of extending the grazing season by more than 4 weeks.

The broad conclusion is that the pastures of Great Britain and Northern Ireland are ready, provided their plant food requirements are met, to carry a far larger head of stock than they do at present and to carry them more

economically. With the present head of stock, imports of concentrated feeding stuffs could be reduced by the larger use of the nitrogen fertilizers which are made at home. With an increased head of stock more concentrated food than is used at present would have to be imported in any case; but the amount required could be made smaller by the larger use of fertilizers on pasture.

SMALL HOLDING EXPERIMENTS

Jealott's Hill small holding. The small holding at Jealott's Hill was established in the spring of 1930, with the object of ascertaining whether a dairy holding situated in a district where milk meets with a ready sale at wholesale prices can be made profitable. Other secondary objects were to ascertain the milk-producing capacity of adequately fed and well-managed grass, and to measure the capacity of the land, not in terms of the grazing season but in terms *of the whole year*. In this respect, therefore, the experiment differs from those previously mentioned. They were designed to show the stock-carrying capacity during the grazing season; this, to show the stock-carrying capacity throughout the whole year.

The holding consists of 46 acres of grass land with buildings for the stalling of 22 cows. It is worked by Mr. Jones and his wife, under the direction of Mr. W. J. Duncan, the farm manager at Jealott's Hill. The only advantages which the holding possesses are to have energetic and hard-working holders and a ready market for all the milk that is produced. The grass of the pastures at the beginning of the experiment was somewhat below average in quality, and little had been done to it for a number of years.

The stocking was done gradually—with Ayrshires—and the full complement of cows was not reached by the end of the year.

It was decided not to employ full intensive management in the first year. A liberal use of concentrate foods was allowed in order to have means of comparing productivity with that of future years when concentrated feeding stuffs would be used in decreasing amounts. Concentrates were therefore fed for every gallon over three and the amount of nitrogen fertilizer which was applied to the grass was kept low, averaging only 1¼ cwt. to the acre: phosphates were supplied to the extent of 8 cwt. per acre.

The holding was carrying at the end of 1931—the year under review—11 cows in milk, 7 dry cows, 1 bull, and 3 yearling heifers bred on the holding. During the year the holding produced 13,204 gallons of milk. Each of the 46 acres of grass used for grazing or hay produced 287 gallons of milk in the course of the year. The experiment shows that slightly less than 2 acres of well-managed grass land are sufficient to supply all the grass and hay required by one cow for the whole year.

Beside carrying stock, 25 acres of the grass land were laid up for short periods and cut. They supplied 38 tons of hay for winter feeding.

The milk sold off the farm amounted to 12,159 gallons, and realized £708. After putting against it all charges, including rent, the small holder's wages and supplies bought in, the profit was £125 (see balance sheet Appendix VII).

Small holdings in England, Scotland, and Wales. The small holders who have co-operated in applying the new methods throughout their several holdings numbered ten

in 1929–30 and fourteen in 1930–1. They were, with one exception, tenant farmers.

It was important that the holdings should be fairly representative of the general run of small holdings in Great Britain, and districts were therefore chosen where groups of small cultivators are already established. For the same reason the more fertile districts were avoided.

Of the fourteen holdings in 1930–1 two were exclusively arable, three consisted of permanent grass only, and nine were mixed holdings. All had this in common—the whole of the produce of the farm was used for the feeding of stock, with the exception in one case of 3 acres of potatoes.

In the arable and mixed holdings temporary grass was used both for grazing and hay. The rest of the arable area grew corn and straw and roots for feeding the live stock.

The total acreage of the holdings in 1929–30 was 348½, and in the following year 513. The holdings ranged from 17 to 60 acres in extent.

In 1929–30 the average stocking was 1 cow to 2 acres. The second year saw a further improvement, and whereas in the former year 200 acres sufficed to carry 100 cows for twelve months of the year, in the latter year the acreage was reduced to 184: that is to say, slightly less than 2 acres sufficed—as on the Jealott's Hill small holding—to carry one cow for the whole year.

In 1929–30 seven, and in 1930–1 eleven, of the holdings were used for the production of milk; the other holdings being engaged in stock raising and butter making. The average milk production in the dairy holdings was 207 gallons to the acre in 1929–30 and 205 gallons in 1930–1; the highest production was 406 gallons to the acre in 1929 and 375 gallons in 1930–1. As was the case at Jealott's

Hill, some of the holders continued to use more concentrates than would have proved necessary, others, however, finding their grass so productive, cut down severely and successfully expenditure on concentrates.

One holding showed a loss in 1929–30 and two only a very small profit in the following year. All the others made a fair profit. After allowing 6 per cent. on the working capital invested in the holding and after all charges, rent, rates, hired labour, &c., the average income for the first year was £3 2*s.* 0*d.* a week and for the second year £3 14*s.* 0*d.*, beside providing in both years the houses rent free.

Although by the nature of the case it is impossible to state what the holders were getting before the experiment began, the fact that two of them have been able to increase their holdings and that all have increased their stock, and taking into consideration that the times during which the experiment was carried out were the most difficult which a farmer has experienced for generations, the experiment shows that a small holder in a suitable district, specializing in produce for which a market exists, can make a living. To the urban dweller a weekly income of from £3 to £4 may seem a poor return for the exercise of so much skill and effort. It is. But given the conditions under which a small holder has to strive for existence, and considering also that he is following a vocation which he loves, it is not unsatisfactory to be able to show that, with the exception of one in the first year and two in the next, a living was made out of these small holdings.

Irish small holdings. Milk-producing holdings in Ireland offer exceptionally good opportunity for ascertaining the financial results which follow from intensive manage-

ment of grass land. The milk is sold to the creamery daily throughout the season, and therefore it is often possible to obtain authoritative information of the amount of milk from any given holding and the size of the weekly cheque the holder receives, and to compare the yields and returns with those produced by the same holding in the previous year.

The trials, the results of which are now to be recorded, were begun in 1929 and continued in 1930. The number of holdings in the former year was 4 and in the latter 15.

TABLE XIII

A Comparison of Results on 15 Farms in Ireland supplying Creameries with Milk before and after adopting Intensive Management

	Before adopting Intensive Management	*After adopting Intensive Management*
Acres	284	196
Total milk sold to creameries	32,146	50,224
Milk per acre . .	113	256
Acres per cow . .	2·36	1·31
Gross returns per acre	£3 13*s.* 10*d.*	£7 16*s.* 1*d.*
Cost of fertilizers per acre	—	£2 1*s.* 8*d.*
Net returns per acre .	£3 13*s.* 10*d.*	£5 14*s.* 5*d.*

The results which are given in Table XIII show that the use of nitrogen and mineral fertilizers, combined with the control of grazing, reduced the acreage required to feed a cow by nearly one-half (from about $2\frac{1}{3}$ to $1\frac{1}{3}$).

Milk production rose from 32,000 gallons on 284 acres to over 50,000 on 196 acres.

Before the new methods were adopted the milk produced

per acre was 113 gallons. Intensive management more than doubled the amount, making it 256 gallons.

The gross returns per acre with which the holder had to be content before he began to improve his pastures were £3 13*s*. 10*d*. They rose to £7 16*s*. 1*d*. Deducting from these sums the cost of fertilizers per acre, the net returns are: before, £3 13*s*. 10*d*.; and after, £5 14*s*. 5*d*. per acre.

Nor do these figures represent the whole of the advantage which accrued to the holders. It so happened that the price paid to holders for milk was on the average 1¼*d*. per gallon less in the year during which the experiment was made than it was in the year before. Had the price been the same for the two years, the net receipts per acre would have been £3 13*s*. 10*d*. before and £7 1*s*. 0*d*. in the year of intensive management.

The stock-carrying capacity of the Irish holdings is very much lower than the average on the holdings recorded in Table XII. The Irish holdings require 1⅓ acres per cow, for the grazing season, whereas, as already shown, the holdings under intensive management in Great Britain averaged nine-tenths of an acre per cow. The explanation is a simple one. Those Irish holdings were, without exception, on very poor land. Land in a very poor state takes time before it reaches the full measure of improvement of which it is capable. How great is the progressive improvement which may be achieved is the subject of Chapter VII. Here it suffices to say that the application of the new methods has increased the holder's returns by 75 per cent. and that were the same methods employed with equal success throughout Ireland the result would be as though by some magical enchantment the grazing area widens and widens until it becomes double, and time for ever

indissolubly linked with it, narrows as space widens, until the future shines on the horizon of the present, glowing in the mellow light of prosperity and contentment.

> Earth's increase, foison plenty,
> Barns and garners never empty;
> Scarcity and want shall shun you
> Ceres' blessing so is on you.

VI

ESTIMATES OF INCREASES IN FOOD PRODUCTION

Basis of estimates. Arable crops. Grass land and live stock. Feeding stuffs. Savings in imported food.

Basis of estimates. The material facts on which any reasoned estimate of increased food production must be based have now been given. They show by small and large examples that big increases are possible on both arable and grass land.

The additional food production from arable land is based on the figures given of the increases actually obtained not only on an experimental scale at Rothamsted and Jealott's Hill, but also on average farms in this country. So far as arable land is concerned there will probably be general agreement among agriculturists that the amount of increase estimated is well within the farmer's power of accomplishment. Indeed it is likely that many practical and scientific agriculturists will regard these increases as under-estimating the capacity of arable land to grow more food.

It has to be remembered, however, that the agricultural land of Great Britain varies very widely in fertility, that weather plays an important and by no means always beneficent part in determining crop yields, and that disease may bring about serious reductions in the yields of crops.

When all these facts are taken into consideration the increases indicated by the figures already given would seem to provide a reasonable measure of what can be done in the immediate future.

The estimates of increased production on grass land are bound to meet with more criticism, for, as has frequently been pointed out already, practical knowledge on the grass-land branch of agriculture is not so advanced as is knowledge of the arable side of husbandry. It is for this reason indeed that the evidence of what grass land can produce has been set forth at some length and in considerable detail.

Farmers who are happy in the possession of naturally fertile grass land will no doubt accept the figures given in the previous chapter as being well within the limits of what grass land can produce; but those less fortunately placed, who farm the poorer grass lands of the country, may be disposed to doubt whether their land can ever be made to produce so bountifully as is claimed for it here. Yet the examples of the increased production which have been obtained on those small holdings in Ireland, on some of the poorest land in these islands, serve undoubtedly to show that it is from the poor as well as the average grass lands that the largest increases over present production are to be obtained.

Therefore, when it is remembered that all save very few of the numerous experiments which have been recorded were carried out not on good grass land but on land of average or poor quality, it must be conceded that, large as the estimated increases from grass land are, they are not sanguine, but sober estimates based on realities.

It would be possible to bring in supplementary estimates to prove that further and not inconsiderable augmentation of food production would presently be possible. But, inasmuch as the figures could at best be only conjectural, it seems preferable not to attempt exact estimates, but merely

to indicate the directions in which further progress in food production may be made.

So much for general considerations: now to the estimates.

Arable crops. *Cereals.* Wheat, barley, and oats are grown annually on nearly 6 million acres. Some of these crops receive already a sufficiency of fertilizers, but a very large proportion of them does not. How sparing is the present use of fertilizers on cereals may be inferred from the fact that the total nitrogen used for crops of all kinds in Great Britain amounts to but little more than half of what should be applied to the cereal crop alone.

The results of both large and small scale experiments and the comparisons drawn between use of fertilizers and yields in different countries (Chapter III) show that the 6 million acres under cereal crops could be made to yield an average increase of 2¾ cwt. of grain to the acre. Straw, although increased also and valuable for feeding purposes and for making manure, is left out of account.

The yield of wheat is raised from 17·7 to 20·3 cwt. per acre; and even so is still nearly 3 cwt. per acre below that of Holland.

Barley increases from 15·8 to 19 cwt. per acre: 4⅓ cwt. less than the yield of Holland.

The oat crop is raised from 14·6 to 17·2 cwt. and exceeds that of Holland. The additional food supplies which these yields provide amount to:

Cereals: 797,000 tons increase,
= 19 per cent. ,,

The average yields are still below those of the Holland Division of Lincolnshire, which, as shown in Appendix IV (Table B), produces 23·1 cwt. of wheat, 19·9 cwt. of barley,

and 22·9 cwt. of oats to the acre. Intensive cultivators, as for example those of the Holland Division and the Lothians of Scotland, are already showing the way which may be followed by farmers generally. Not all land can produce bountifully, but the average suggested is after all a modest one and certainly capable of achievement.

Potatoes. Great Britain and Northern Ireland grow annually 776,000 acres of potatoes. The average yield is small—$6\frac{1}{3}$ tons to the acre. The potato crop responds generously to fertilizers. This is true even on the poorer land, and it is certain that the yield could be raised by not less than 1 ton to the acre, which gives an increase of:

Potatoes: 776,000 tons.
=18 per cent.

The 400,000 tons which used to be imported each year are no longer wanted. Measures must be taken to absorb the surplus provided by good years; but Holland and Germany have already shown how such measures may be put into practice, and there would seem to be no reason why subsidiary uses should not be found for the surplus potato crop of this country.

Under the present chaotic conditions a large crop brings little or no benefit to the farmer. It must be made to do so, if increased production is to become a national aim.

Sugar beet. There are 349,000 acres under sugar beet. It is a crop comparatively new to this country and, partly for this reason and partly because of climate, the yield of sugar is not so high as it is in some of the beet-growing countries of the Continent. Better organized than most branches of arable cultivation, the sugar-beet industry is already doing much to improve cultivation, and its efforts

are bound to lead to a marked increase in the yield of the crop. Knowledge of the need for a right balance between the nitrogen and potash fertilizers applied to sugar beet, when it becomes general, will help considerably in raising the level of production.

Many growers of sugar beet already use fertilizers, but if the use were universal—and there is no reason whatever why it should not be—the present yield of 24·4 cwt. of sugar to the acre would rise to 30·1 cwt.

The Jealott's Hill experiments already described gave yields of the latter amount. They were obtained on land which is by no means ideal for sugar beet, and may therefore be regarded as indicating the average increase of which the crop is capable.

Sugar beet: 99,000 tons sugar increase,
= 23 per cent. „

Mangolds, swedes, turnips, &c. Mangolds are grown on 328,000 acres; swedes and turnips on a little more than 1,000,000 acres.

The present yield of mangolds is raised from 19 to 20½ tons to the acre: an increase of 1½ tons. Swedes and turnips yield 15 instead of 14 tons: an increase of 1 ton to the acre.

Mangolds, swedes, turnips, &c.: 1,699,000 tons increase,
= 7 per cent. „

The other farm crops, peas, vetches, kales, &c., are grown over relatively small areas and are not brought into the account, neither are the market-garden crops, for, although of great and increasing importance, it is not possible to say what further increases could be produced from these already generally intensively cultivated crops.

It is, however, certain that the restrictions relating to the

importation of horticultural produce which are now in force will lead to an extension of the acreage under market-garden and other horticultural crops, and it is no less certain that with the prospect of enlarged markets cultivation will become yet more intensive.

Fruit crops would also be greatly increased. The small fruits are known to respond very generously to fertilizers, and experiments with top fruit show that they also respond, but knowledge of the magnitude of increase which could be brought about by more intensive cultivation is not at present sufficiently precise to allow of estimates to be made. Such experiments as have been carried out show, however, beyond all doubt that far more fruit could be grown at home.

The hay crop. Nearly 5 million acres of permanent grass are reaped for hay every year. The average yield is about 1 ton to the acre. Nitrogen and mineral fertilizers increase it by nearly 50 per cent., raising the yield from 20 to 30 cwt. per acre, a total increase of 2,219,000 tons.

The temporary grass sown down in the course of the rotation is made to yield an increase of 10 cwt. to the acre; the present average of 28·7 is raised to 39 cwt. to the acre: an addition of 1,200,000 tons of hay.

Hay (from permanent and temporary grass)
3,419,000 tons increase,
= 41 per cent. ,,

The increased production from these crops is:

Cereals	797,000 tons	
Potatoes	776,000 ,,	
Sugar beet	99,000 ,,	(sugar)
Mangolds	525,000 ,,	
Swedes and turnips	1,174,000 ,,	
Hay, permanent grass	2,219,000 ,,	
,, temporary grass	1,200,000 ,,	

These figures, save those relating to potatoes and sugar beet, must now disappear from the estimates, because the food contained in the cereals, mangolds, turnips, and hay will be used for the increase of live stock, and the food incorporated in the bodies of farm animals can no longer be regarded as having a separate existence.

The increased head of poultry will, for example, require all and more than all of the 192,000 extra tons of wheat, and the greatly increased number of pigs kept in the country will require all and far more than all the 206,000 tons additional barley which is grown.

Grass land and live stock. The animal side must now engage attention.

The head of live stock in the country can only be increased economically by making grazing lands more fertile. It has been shown already that they can be made more fertile.

The experiments described on p. 70 prove that ten cows grazing intensively treated pasture may be fed during 26 weeks of the year on 9 acres of grass land. The Irish small holdings, see p. 74, show that under intensive management $1\frac{1}{3}$ acres carried the same number of cattle as did $2\frac{1}{3}$ acres before the experiment began, that is to say, for every four cows carried under ordinary grazing, seven are carried on the same area under intensive grazing.

Intensive grazing on the fairly good pastures at Jealott's Hill has increased the stock-carrying capacity by 60–75 per cent. By far the larger proportion of grass land in this country falls into one or other of these two categories—poor or fairly good—and, therefore, taking the average figure, the stock-carrying capacity of the country as a whole could be raised immediately by 67 per cent. But the land at the

present time is not stocked to its full capacity. It is understocked certainly to an extent of not less than one-third. It may therefore be concluded that the number of cattle kept in Great Britain and Northern Ireland can be doubled. Granting that this may be done, it must be admitted that to double the number of cattle is a much slower operation than to double the amount of food required for their grass and hay ration. The increase in cattle if attempted at too quick a rate would prove costly. On the other hand, it need not take an unduly long time. If strenuous steps were taken to facilitate the rate of increase, the doubling of the present head of stock might be effected in the course of a decade. Among the more important steps which would have to be taken are the provision of the necessary buildings and the organization of stock raising on a large scale. Yet another is the provision of adequate water-supplies. There are to-day innumerable farms both in grazing and arable districts so ill supplied that the cost of carting water is a serious charge and one which no well-organized country ought to impose on the farmer.

It will doubtless be urged that so large an increase as that suggested in the estimate would add to the risk of disease in farm live stock. It may be pointed out, however, that there are parts of the country in which the stocking of cattle is as high as that now contemplated, and that there is no reason to believe that live stock in those districts is more subject to disease than it is where the animals range over large spaces of relatively infertile pasture.

Sheep stand in this respect in a different category. They are more prone than cattle to attacks of parasitic diseases. This is especially the case in districts already heavily stocked with sheep. Repeated grazing on a restricted area

throughout the whole of the season increases the risk of infection. Once, however, this fact is recognized, the risk may be discounted. The difficulty has been met and has been overcome. No harm follows from two or three grazings of the same ground in the early part of the year, but after June sheep must move on to fresh ground, which has in the meantime been prepared for them. Where both cattle and sheep are kept, and the stocking with sheep is in consequence not so heavy, infection is found to be no more prevalent than it is under ordinary conditions of grazing.

The estimate provides for the present head of cattle, 7,965,000, increasing year by year until it becomes 15,930,000. The increase in sheep would be less. Many are grazed at present and would continue to be grazed on those rough grazings to which reference has so often been made. The grass of rough grazings is known already to respond to fertilizers (see p. 99), but the economic use of fertilizers even on the better parts of the rough grazings has not yet been explored sufficiently to justify any estimate on their account.

Apart, however, from this potential source of increased food for live stock, the application of fertilizers to grass provides food sufficient for 34 million sheep instead of the present 24 million, an increase of 10 million (see Appendix IX).

Intensively treated grass land, by making possible a progressive increase in the head of cattle until the number is doubled, provides for a proportionate rise in the output of milk and beef until the supplies are doubled.

More thrifty use of surplus grass, discussed on page 100, provides additional winter food for cows and farm animals

generally. The largely increased production of cereals paves the way for the British farmer to increase threefold the 3 million pigs which he now keeps, and helps towards raising the number of poultry from the present figure of 60 million to 110 million.

Feeding stuffs. The larger output from pasture land supplies more food for live stock, but the increase in cattle, sheep, pigs, and poultry which is within the range of accomplishment is so great that even the augmented home supplies both from arable and grass land would not be nearly enough to support it.

TABLE XIV

Increase in Food Production (Great Britain and Northern Ireland)

Food	*Present. Per cent. of total consumption*	*Production as increased by the use of fertilizers. Per cent. of total consumption*	*Increase. Per cent. of total consumption*
Meat, including eggs	41	91	50
Dairy products	39	77	38
Vegetables, fruit, &c.	79	83	4
Sugar	24	30	6
Cereals	15	15	—

The increased production of cereals, 797,000 tons, does not appear in the table because it has been taken into account in the food of live stock and hence in the increased production of meat, milk, &c.

Any large increase in live stock must mean a large increase in the consumption of feeding stuffs. The present importation of feeding stuffs (see Table XV) is upwards of 5 million tons. The cattle and other stock of the estimate require more than double that amount. Imports of feeding stuffs would rise to little short of 11 million tons: a greatly

augmented importation of raw materials, out of which are to be built the finished products of British agriculture: milk, meat, butter, cheese, and eggs.

Prospective production of these products is compared with present production in Table XIV; and the extent to which increased production of the higher priced agricultural products affects the importation of concentrated feeding stuffs is shown in Table XV. The increases in the essential food materials, protein, fats, and carbohydrates, are shown in Chart VII, which also indicates that the food which would be produced at home provides 55 per cent. of the total requirements measured in terms of energy.

TABLE XV

Concentrated Food for Live Stock

In thousand tons

	Present			*Total requirements of live stock increased according to the estimates*		
	Total	*Home*	*Imported*	*Total*	*Home*	*Imported*
Corn	5,220	3,000	2,220	9,120	3,797	5,323
Offals*	1,700	250	1,450	3,264	250	3,014
Cakes* and other meals such as brewers' grains, sugar-beet pulp .	2,190	490	1,700	3,050	490	2,560

* A large quantity of offals, cakes, and meals is manufactured from imported wheat, oil seed, &c., and is, therefore, classed under imports.

Home-produced meat is served on every table throughout the land for all the year, save for a short five weeks. It is rare to eat an egg, rasher of bacon, pork or mutton chop which has been imported. All the meat and all the vegetables, including potatoes, which grow in this country

come to the table fresh from the fields where they grow, with their vitamins intact; but the grain ships bringing breadstuffs from overseas are not less numerous, and many more than come at present are wanted to carry the addi-

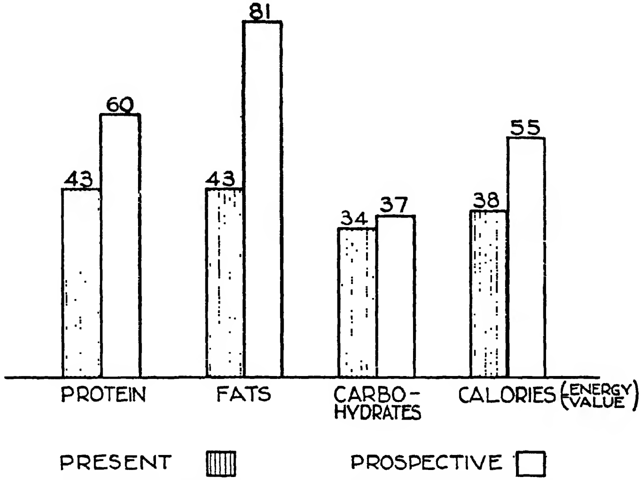

CHART VII. Present and Prospective Home Production expressed as Percentages of Total Requirements.

tional feeding stuffs for the support of the numerous flocks and herds which graze the countryside.

Savings in imported food. Great Britain and Northern Ireland, instead of producing 38 per cent. (see footnote, p. 5) of all the food they need, now raise more than half—55 per cent.

The increased production, 17 per cent., leads to a large decrease in the sum paid for imported food. In order to frame an estimate of the saving in payments made overseas it is necessary to compute not only the values of the

increased home-grown products, but also those of the raw materials required for their production. When this is done and allowance is made for the additional feeding stuffs for live stock, potash fertilizers and phosphates required to supplement home supplies, the measure of the saving can be worked out in accordance with the values of the imported foods. Taking the world's worst prices—those of 1931—the annual saving amounts to 96 million pounds sterling; on the basis of 1930 prices to 124 million, and on the basis of the average prices for the seven years 1924–30, to 126 million pounds sterling. The bill paid by the nation for imported food is reduced by not less than 100 million pounds sterling and the symmetry of the social structure of the country is restored.

PART II

FURTHER MEANS OF INCREASING FOOD PRODUCTION

VII

THE IMPROVEMENT OF PASTURES: PRESERVATION OF GRASS FOR WINTER USE

Clover and nitrogen. The amelioration of poor pastures. Short grass hay. Ensilage. Grass drying. Feeding value of dried grass.

THE IMPROVEMENT OF PASTURES

THE knowledge that the pastures of Great Britain and Northern Ireland do not yield the maximum of which they are capable, because of the widespread insufficiencies of the nitrogen and mineral foods of the soil, is ripe for practical application. There are, however, two firmly established but ill-founded beliefs which stand in the way. It used to be and is still thought that nitrogen fertilizers, though they increase yields, have in the long run a damaging effect on pastures. The equally ill-founded belief still persists that nitrogen fertilizers weaken the growth of clovers in pastures. It is easy to see how these beliefs arose. A dressing of nitrogen fertilizer is applied to a meadow laid up for hay. It increases the yield, but the aftermath is often poorer than it would have been if no nitrogen had been given for the hay crop. The clovers have been weakened so much that they seem almost to have disappeared. These observations made on meadow land are assumed too hastily to apply to pastures, and herein lies the origin of the tradition that nitrogen fertilizers bring about a deterioration of grass land and particularly of the clovers which grow in it. Closer observation and experiments prove the contrary.

They show that it is not nitrogen but neglect which

brings about deterioration in grass land whether it be meadow or pasture.

In general practice where no nitrogen is given either for the hay or for the aftermath, both are starved and yield poor crops.

Where nitrogen is given for the hay crop only, that crop is well fed and yields bountifully, but the nitrogen given has in part been used for making hay and in part has become locked up in the soil (see p. 165). The aftermath, starved of nitrogen, grows but poorly and yields a crop sometimes scantier than that from the no-nitrogen meadow.

In what presently will be recognized as the correct practice where good crops of hay and aftermath are required, nitrogen is given for the hay crop and also for the aftermath. Both yield abundantly.

The same relations between growth and nitrogen obtain in pastures. Growing grass is constantly removing nitrogen from the soil. There comes a time, which occurs every season on almost all the pastures of this country, when growth flags because there is not enough nitrogen to sustain it. If nitrogen is added, growth is reinvigorated. Provided, therefore, that no shortage of other plant foods is allowed to occur, yields are maintained and the pasture itself, far from decreasing, increases in fertility. To maintain the contrary is to believe that the only way to keep anything in health and vigour is to withhold the materials out of which vigour and health are constructed.

Clover and nitrogen. The opinion that nitrogen depresses clovers in pastures must now be discussed. There is a meadow in June: the grasses are standing dense and lush, a foot or more in height, and beneath the deep shade which they throw the clovers are struggling with

but little success to keep themselves alive. They are not troubled by lack of nitrogen. The grasses can have all there is: the clovers make their own, synthesizing it from the free nitrogen of the air. But nitrogen is not the only need of a plant, nor can it get from the soil the starchy and sugary foods out of which it builds its body and by means of which it does its work. Light is the agent which the plant employs to run its green leaves as factories for the making of sugars and starch. The clovers close to the ground, though they elongate their stalks as much as they may in the attempt to satisfy their cravings for light, cannot get enough sunshine to keep their leafy sugar factory running at anything like full make. Some plants are able to make the bricks of carbohydrate with very little of the straw of light. They are the shade plants accustomed to make the best of the dark places of the earth where they abide. The clovers are not of them. They like plenty of sun, and so when the hay is mown their sorry plight is an unmistakable sign of the defeat which they have suffered in the unequal struggle with the tall growing grasses.

A plentiful supply of nitrogen was no good to them. Its presence affected them neither one way nor the other. They did not want it, but were by no means incommoded by its presence. They were, however, incommoded by the shade in which they had to live, and have sustained a serious check to growth. But, as any inexpert gardener must admit, plants take a great deal of killing. Regaining at last their place in the sun, the clovers will soon renew their vigour and the sooner if they are aided by good management (see p. 121). The farmer, therefore, need not worry because the clovers which were strong before the field was laid up for hay look so weak after the hay has been carted.

The temporary depression of the clovers in meadow land is the father of the belief that nitrogen is the ruin of the clovers in a pasture.

The nitrogen produces a more luxuriant crop of grass, the shade in which the clovers have had to live is deepened, and in the dimmer light they make a yet poorer growth. But this does not happen, or should not happen, in the pasture. Encouraged by nitrogen, the grasses grow, but they are eaten down before they begin to rob the clover of the light it needs. And so, with plentiful supplies of mineral plant foods, the clovers are easily able to hold their own even in pastures which are supplied successively year after year with so many as three or even more dressings of nitrogen. As will be shown presently, management may be made to turn the scale in the conflict between clovers and grasses. It decrees that here in this pasture grasses shall predominate. They do. That there clovers shall all but monopolize the ground. They obey.

An experiment made at Jealott's Hill in 1930 demonstrates that shade decides the issue of the contest between grass and clover. A field of arable land was sown down to pasture. The seeds mixture contained grasses and clovers. In the first year of the pasture a part of the field was used for an experiment which involved the frequent cutting of the sward. The cut area and that neighbouring it received phosphates and heavy dressings of nitrogen. The soil contained ample supplies of potash. In the latter part of the year the seven-times cut area had become a predominantly clover sward. The repeated cutting prevented the grass from robbing the clovers of light. The clovers flourished. The neighbouring area was cut only twice. The grasses grew more vigorously and taller before and between the

cuts and, as a consequence, the proportion of clover was so small as to make it difficult to convince any one that the same mixture had been sown in both areas, and still more difficult to persuade any one that both areas had received equally large quantities (3 cwt. to the acre) of nitrogen fertilizer.

The much cut area represents the constantly and closely grazed pasture. Well managed, grazed and rested judiciously, clovers do not decrease, but may be made, if need be, to increase.

The larger contention that intensively treated pastures gradually undergo deterioration rests on no experimental evidence whatsoever. At Tollesby Farm, in Yorkshire, intensive grazing has been practised for six years (see p. 63). The pastures have been dressed annually and heavily with nitrogen. They are better to-day than any in the neighbourhood. The pastures at Jealott's Hill, on which intensive cultivation has been carried on for four years, have been improving all the time. It is safe to say that they will go on improving, and that the application of nitrogen fertilizers will prove in the future, as in the past, a powerful agent in promoting the improvement.

The amelioration of poor pastures. The poor pastures of Great Britain are many and various. There are those on heavy soil, which have made themselves from derelict arable land, gradually becoming more or less clothed with a sward of varying degrees of poverty. Similar tumble-down pastures are to be seen on light land and on the chalk.

If any one climb from the valley up a mountain in England, Scotland, or Wales, he sees a succession of pasture lands. The lowland gives rich grazing. It is

fertilized from above. The rains are always washing down from the hill-sides large supplies of plant food. The better grasses, those which thrive on fertile land, grow there. Yet even these pastures respond to fertilizers and to good management. Above them, extending up the hill, are pastures of a lower grade, containing grasses of which crested dogstail is the chief. Make good the shortage of plant food from which they suffer and the pastures of the foot-hills are transformed. The better yielding grasses, rye grass and cocksfoot, come in, take up their abode, thrive, and yield more and richer grazing.

Climbing higher, the second zone comes into view. The land is now so poor that grasses inured to poverty can alone persist. Such are the bents. Only during two or three months of the year are they well nourished. They show satisfaction by their dark-green colour. Soon a brownness steals over them and their increasing starvation betrays itself in the ashen grey pallor of their autumn and winter state. In the brief season of their growth, the bents give good feed for cattle and for sheep, but for the rest of the year there is no life in them. When the poverty of the soil is relieved, the bents decrease. They are so inured to hardship as to be unable to enjoy prosperity so complacently as those which were born to it. They are ousted by more nutritious grasses. Crested dogstail and the clovers which are already there, albeit in a poor and phosphate-starved condition, so increase that in the course of a year or two they more than double the value of the pasture.

Above the zone of bents heather may appear and in its young stage gives good grazing; or else up to the hilltop are to be found only the poorest grasses of all, nardus or molinea, with a life so brief that from start to finish it

lasts a bare eight weeks of the year. They, like the bents below them, only monopolize the ground because it is unfit for anything else to live in. Change the conditions, supply food, and the plants on the lower slopes climb up and begin to dispute the ground with nardus or molinea, now there is something worth disputing about. It is slow work creating homes on the high hill-sides for the lodgement of the worthier grasses—a kind of slum clearance, but an experiment started in 1928 on a bleak hill-side in the West Riding of Yorkshire shows that it can be done.

In that year nardus monopolized half the ground, the other half being given over to bent, fine-leaved fescue, woodrush, sedges, and moss. The ground was limed and supplied with nitrogen and mineral plant foods. The nardus began gradually to disappear until after three years it occupied little more than half the ground it held at the beginning of the experiment. The place which it resigned was taken by bent, fescue, crested dogstail, Yorkshire fog, and clover.

How to speed up the process of reclamation and how to discover whether it can be done economically are problems which deserve investigation. Another experiment, begun in the same year and on the same hill-side, was made by first burning the native grass in early spring, harrowing drastically, liming, supplying all the plant foods, and sowing with a mixture of grasses and clovers. The result is even more promising than that of the former experiment. Rye grass, cocksfoot, and clover are now successfully established.

Prominent among these pioneering experiments to discover what can be done to make rough grazings fertile are those carried out by Professor R. G. Stapledon on the Welsh mountains.

Many means must be tried before the best can be discovered, but experience shows that whatever the means there must be no omission to supply the ground with nitrogen and phosphatic foods of which it contains such meagre stores. When experience has discovered the best way, it will still remain to prove that the reclamation can be carried out on a large scale on economic lines.

THE PRESERVATION OF GRASS FOR WINTER USE

The better utilization of surplus grass—grass not used for grazing—offers a further and powerful means of increasing food production. Every year, despite inclemencies of weather, 7 million acres of meadow land are cut for hay in Great Britain. This acreage includes both temporary and permanent grass. The average yield from the former is 29 cwt. per acre: from the latter 21 cwt., so that the total hay crop amounts to 8 million tons. Its value varies greatly according to the kinds of herbage, their states of growth, and the conditions under which the hay is got. This most important of all crops, although indispensable to the farmer, is not of high feeding value. A cow fed during the winter solely on ordinary hay maintains its body weight, but yields no more than a gallon and a half of milk a day. For any higher yield concentrated feeding stuffs, which are mainly imported, must be supplied. The question therefore arises whether the quality of hay can be improved or whether other methods of supplementing or replacing hay-making can be adopted.

Four methods of preserving grass other than by ordinary hay-making are known: the making of short grass hay, the conversion of grass into ensilage, grass drying, and a new chemical method which, though it holds out promise of

success, has not yet been tested in this country and must therefore be omitted from consideration.

Short grass hay. The increased earliness brought about by the use of nitrogen fertilizers results in most seasons in grass reaching a height of 6 to 8 inches by or before the end of May. Although grass cut at this stage suffers in the course of natural drying, as that used for ordinary hay-making suffers, the final product is better than ordinary hay. It contains a larger amount of nitrogenous foods—the most expensive kind of animal food—and it has all the essential animal feeding stuffs in a better proportion, and so is a more balanced food than ordinary hay. It will provide maintenance and production rations for a milch cow of moderate yield.

The short grass hay crop is smaller than the ordinary hay crop, but even so, the balance of advantage is in its favour and is turned still further when, in a propitious season, a second cut is taken and converted into hay or ensilage.

There are, however, practical objections to this method of better utilization of grass. The chief is the dislocation of farm labour which it entails. On the mixed farm the claims of the arable land are paramount and may make it impossible for the grass to be cut at the right stage. On the purely grass-land farm, however, this difficulty does not arise and it should be possible to use some of the meadows for the production of short grass hay. But hay-making is in any case troublesome; bad weather intervenes, puts a stop to operations, increases the cost, and reduces the value of the product. It is therefore of practical interest to state the results of experiments which have been made on an alternative method of preserving surplus grass as ensilage.

Ensilage. The pioneer work was done by Professor J. P. Drew, of Dublin, who has made numerous experiments in the making of grass ensilage in tower and in pit; other experiments using the simple method of stack silage have been carried out at Jealott's Hill.

The principles of silage making are simple; but the practice requires experience. Grass put in a heap ferments. The temperature rises and the grass is partially cooked. When left to itself cut grass is attacked by all sorts of micro-organisms. It decomposes, and its feeding value is lost. If, however, it is stacked skilfully, heating and activity of micro-organisms may be so controlled that the grass is converted into ensilage, a greenish-brown material, which preserves much of the food present in the original grass. In this condition the stack will remain for an indefinite time, and the ensilage may be used during the winter for all those purposes to which hay is put.

There are three ways in which ensilage may be made: in a tower, pit, or stack.

The making of stack ensilage requires more attention and skill than either of the others, but experience shows that it is not difficult to master the art. The stack is built up gradually, neither too fast nor too slow, the rate of building being so managed that the temperature in the middle of the stack is kept at about 49° C. (120° F.). Rough protection is provided on the windward side, otherwise the heat necessary for the ensilage process is lost. Special care is taken to ensure that the grass is well consolidated at the edges and well trimmed off at the sides.

The composition of ensilage compared with that of hay of average quality is shown in Table XVI. As the figures indicate, hay and ensilage have about the same feeding

value. Experiments in feeding ensilage to stock prove that cows eat it readily, and that it may be used to replace hay in their winter ration.

TABLE XVI

Analyses of Stack Silage and Hay both made from Intensive Grass cut at the same time

	Silage	*Hay*
	Per cent. of dry matter	
Ether extract	3·68	1·82
Fibre	27·88	26·37
Crude protein	17·37	16·25
Ash	11·38	10·39
Nitrogen-free extractives	39·79	45·17
Calcium (CaO)	1·18	0·85
Phosphoric acid (P_2O_5)	1·04	0·79
Moisture in fresh material	80·4	13·5

Ensilage has several advantages over hay. Bad weather does not interrupt the making of it. Late summer grass can rarely be made into hay. It is easily made into ensilage.

There is no very great difference in the composition of ensilage made by the three ways already mentioned: in silo, pit, or stack. The stack is the cheapest method. The tower silo is expensive but gives a more uniform product. The pit method is good, but requires labour for excavation.

The making of ensilage presents no practical difficulty that may not be overcome by care and common sense. A small holder, inexperienced in it, found himself in the latter part of 1930 with 11½ acres of grass which it was impossible either to graze or to turn into hay. He was advised to make a stack of ensilage and shown how to do

it. The result was that the ensilage which he produced from surplus grass saved him from buying hay.

Grass ensilage, although only beginning to be made in this country, is already part and parcel of the New Zealand grass-land farmer's system. If it were used here, ensiling would be the means of preserving much grass which is now wasted.

Ensilage is valuable not only during the winter but also in spring and summer spells of drought. Dairy cows are at pasture: they become accustomed to the summer grass; drought intervenes and cuts off supplies. No better food can be given to the dairy herd during this period than one based largely on ensilage, supplemented, of course, with concentrated feeding stuffs rationed in accordance with the milk-producing capacity of the cows.

Ensilage making, however, does not get rid of the waste inherent in hay-making. The loss even when ensilage is well made amounts to 20 or 25 per cent., that is, much the same as in the making of hay.

Grass drying. Grass drying saves all waste; but although grass which has been dried preserves the feeding value of fresh grass, it has yet to be shown that it can be done economically on the farm or in the factory.

Drying was first suggested in 1927 by the late Professor Wood and his colleagues of the School of Agriculture of the University of Cambridge. In that year Professor T. B. Wood made a few grass cakes by drying and pressing fresh grass. They were green, of an agreeable odour, and their making proved that there is no mechanical difficulty in the manufacture of grass cake.

At Professor Wood's request the staff of Jealott's Hill, in co-operation with the research staff of Billingham—the

place where synthetic nitrogen fertilizers are made—produced several hundredweights of grass cake made from young grass. The grass cakes, some of which are still kept at Cambridge, show no deterioration. They were sent to the Agricultural Department and were used in a feeding trial. Cattle fattened with the ordinary concentrates, together with accessory foods such as roots and straw, were compared with other similar animals which received no concentrated food but were fed on grass cake together with a similar ration of straw and roots. Those fed on grass cake fattened as well and finished as well as those which received concentrates.

The feeding value of dried grass having been proved, the problem became one of finding out the cost of drying young grass. Several types of drier were installed at Jealott's Hill, and from trials conducted by Mr. H. A. N. Dellow, a member of the Billingham staff, it was found that for small-scale production the band drier, a very common type, is serviceable.

In the band drier grass is fed to and carried along a continuous wide perforated metal band, over and through which passes hot air from an ordinary coke fire, which subjects the grass to an initial temperature of about 200° C.

Experiments have shown that the product is perfect in every way. It retains all the food substances and vitamin content of fresh grass, and, no less important, is just as digestible. It is bright green, scarcely distinguishable from living grass; somewhat brittle, easily ground, and no less easily baled (for chemical composition see Appendix XI).

Whilst these experiments were going on, methods of cutting and collecting the young grass were devised. It

seemed at first that there might be difficulty in cutting and picking up grass of about 6 inches in length, but a cutter and elevator made at Jealott's Hill proved that the difficulty does not exist. The implement consists of a tractor drawing an ordinary horse mowing-machine, which does the cutting. The grass, as it leaves the cutter bar, is picked up by the elevator—an endless chain provided with prongs. The elevator discharges the grass into a light trailer which, when full, is detached and drawn either by tractor or horse to the drier. The implement works so satisfactorily that, even during wet weather, 16 cwt. of grass are cut and picked up in from 10 to 15 minutes.

The experimental drier with an output of only 6 cwt. a day is too small to give a fair measure of the cost of producing dried grass. The two men which it requires could manage a drier with three times the output.

In spite of its shortcomings, the experimental drier was used to get a rough estimate of production costs. The result is that after making liberal allowance for all charges, depreciation, production of grass, rent, and overheads, the cost works out at £8 per ton. The present price of concentrated feeding stuffs of equivalent food value is about the same. For example, palm-nut kernel costs £8 6*s.* on the farm, bean meal £8 10*s.* Taking all the facts into consideration, it may be said that artificial drying of grass gives promise of becoming a profitable means of preserving the surplus grass of the farm.

Further experiments in methods of drying are now being made at Billingham; and Jealott's Hill is carrying out comprehensive tests of the feeding value of dried grass.

The existing machine, used continuously throughout the

latter part of 1931, produced 4 tons of dried grass. Some was converted into meal and the rest stacked under cover for feeding trials. The grass meal is being used in poultry trials, it having already been shown that dried grass is at least the equal of alfalfa meal, which is at present imported to the extent of 20,000 tons per annum for poultry feeding.

Feeding value of dried grass. The bulk of the four tons of dried grass produced during 1931 is being used in a feeding trial with dairy stock. The objects of the trial are to ascertain whether dried grass can replace the ration of concentrated food usually supplied to cows during the winter, and to discover whether butter made from the milk of cows fed on dried grass equals in quality butter made from summer grass. The trial has been running three months. It will be continued, and not until the trial is finished can any convincing conclusions be drawn from it. It is, however, possible to say that the cows fed on dried nitrogen grass have given so far a consistently larger yield than those fed on dried grass from fields which received no nitrogen, and that they are producing rather more milk than are the cows fed on a standard winter dairy ration. Even more emphatic is the effect of dried nitrogen grass on the quality of the butter. The nitrogen butter has a richer yellow colour and a flavour superior to that of the butter produced from the milk of cows fed on the standard ration or on no-nitrogen grass. Dried nitrogen grass produces summer butter in winter.

If, as seems probable, grass drying proves to be profitable, this method of preserving surplus grass will add, in a measure achievable in no other way, to the food-producing powers of the country.

The feeding value of dried grass measured by the

digestible protein which it contains, is three times that of ordinary hay.

An acre of meadow land produces, at an outside figure, $1\frac{1}{2}$ tons of hay. Its aftermath, which is either cut or grazed to cattle, yields something less than another ton. Therefore the productivity of an acre of grass land may be taken to amount on the average to two tons of hay.

An acre of grass land with adequate supplies of nitrogen and mineral foods produces, as the figures obtained at Jealott's Hill show, three tons of dried grass.

Dried grass contains three times as much nitrogenous food as does good average hay.

Present productivity (hay) stands therefore to possible productivity (dried grass) as 2 : 9.

Were grass drying found to be economical, its application generally throughout Great Britain would treble the home-supplies of food for the winter keep of farm animals.

If means are indeed found to make grass drying profitable, the process will in the near future supplement and may, in bad seasons, supplant the ancient, picturesque, but precarious practice of hay-making. The landscape will be despoiled of its hayricks, but the farmers of Great Britain will have made the largest possible contribution to reducing the cost of imported animal food.

The drying of grass would be accompanied by the drying of other crops, and the small farmer, or groups of small farmers, might be able to make the same use of crop drying as is beginning to be made already on the large mechanized farms of this country.

Inasmuch as the estimates in Chapter VI deal with the returns which fertilizers can give in the immediate future, no allowance is made in them for this large potential

increase, but the magnitude of the increase possible under a general system of grass drying may be indicated. There are 7 million acres of aftermath in Great Britain. Much of this late grass crop remains perforce unused. There are not enough cattle to graze it. The weather is unpropitious for hay-making.

An acre of aftermath grass yields on the average 15 cwt. measured in terms of hay. If but half the aftermath were saved by drying, it would provide an additional 2½ million tons of concentrated food for the winter feed of farm animals.

Whether grass drying prove profitable or not, the discovery of the potent influence of nitrogen combined with mineral fertilizers on grass land marks the beginning of a new era in agriculture. The day of nitrogen starvation of grass land is past; the day of nitrogen plenty has dawned.

VIII

THE MANAGEMENT OF GRASS LAND: THE ROTATION OF CROPS APPLIED TO GRASS LAND

Principles of intensive management. Rotational grazing. Strip grazing.

THE MANAGEMENT OF GRASS LAND

Principles of intensive management. The intensive management of grass land consists in the application on the farm of three principles, each of which has been proved to be true. They are:

(1) Young grass is a complete and sufficient food for cattle and sheep.

(2) Grass supplied with mineral foods and dressed twice or thrice in the course of the year with nitrogen provides more plentiful food than does the young natural grass.

(3) Controlled grazing ensures successive crops of young grass over a period longer than the normal grazing season. When eaten down in the young stage grasses produce new crops of young leaves; but left to themselves they go on growing, and as they become older decrease in feeding value.

Rotational grazing. German agriculturists were pioneers in applying these principles to practice. Professor Warmbold and his colleagues laid down experiments drawn on somewhat rigid lines which showed that results of great practical importance follow from the controlled grazing of properly fertilized pastures. Their experiments and those started in this country in 1926 were carried out in the following way. A series of six or eight fields of approximately equal size, adequately fenced and supplied

with water, is set aside for grazing. The total grazing area is made to bear a definite relation to the number of animals that are to graze it. For example, an area of 60 acres divided into six fields each of about 10 acres will suffice for 100 head of cattle. The fields are grazed one after the other. The grass grazed is always young—4–6 inches in height. The grazing animals are of two ranks. In the case of a dairy farm the leaders are milch cows. Before they have grazed a field down, the second field is ready. It received its nitrogen a week or so later than the first field. Withholding the nitrogen has delayed growth till it is wanted. The leaders, after four or five days grazing on the first field, move on to the second and the followers take their place. The latter are animals of less value from the production point of view—dry cows, store stock, horses—which make good followers—pigs, or, best of all, sheep. Since the followers only get what the leaders have left, some accommodation land is provided for them in case of need. The number of followers is adjusted to the amount of grazing left for them by the leaders. Their business is to bare down the grass evenly, but not too hard. So the procession proceeds from field to field—a grazing circus!

So soon as the followers have done their work, the field is harrowed, if it needs it, and either then or later in the season, according to the growth which the grass is making and the amount of nitrogen given in the first dressing, the field receives a second dressing of nitrogen. In all, each field gets two, three, or, in exceptional cases, four successive supplies of the fertilizer.

The other food requirements of the pasture are supplied before the grazing begins: a winter application of lime, if the land requires it, and a later winter dressing of

phosphates and potash; or else all the three plant foods are supplied together in early spring.

The system in its original rigid form requires a subdivision of the grazing area into fields of approximately equal size. This, although costly, has the compensating advantage of permitting a relatively easy control of the grazing. Control is, in any case, not easy to exercise by the beginner and is made more difficult if the fields are of very unequal sizes.

The German initiative in the practice of intensive grazing quickly passed to this country. For no one concerned with the advancement of agriculture could fail to appreciate how great must be the advantage to the farmer if the benefits conferred by it could be realized here.

Trials were begun in 1926 on Mr. W. Brunton's farm at Tollesby, the late Lord Melchett's farm at Melchet Court, and Captain F. Graham's farm in Cumberland.

The results proved that the sytem is workable; and they also led gradually to the accumulation of experience permitting of simplification of the original somewhat hard-and-fast scheme. It was found, for example, that a farmer who had applied it for a season or two could exercise satisfactory control of the grazing even though the fields differ widely in size. This more elastic arrangement has been tried and proved to be workable at Jealott's Hill, where the grazing is carried out in a series of fields varying from four to eighteen acres in extent. Needless to say, this modification makes intensive grazing easier for farmers to adopt. It saves cost of fencing and of watering, which farmers even when convinced of the value of the system cannot always afford to incur.

In the course of the experiments it was soon discovered

that the needs of grass for phosphates and potash are only less great than they are for nitrogen. Phosphates and potash given during the autumn were often found to have been used up completely by the end of the following summer. The grass became poor, and until the cause of its poverty was discovered the system stood condemned. When, however, the deficiencies in mineral plant foods were made good, it was found that the grasses recover and that the condemnation was premature.

Again, over-insistence on the principle that the grass grazed must be young led to an over-use of followers. They were kept on the pastures too long and bared it down too much. They themselves suffered from shortage of food and the grass received a check from which it took long to recover; but when the common-sense rule that it is unwise to work a willing horse to death was brought into operation, and the grass was grazed less heavily, it suffered no check but grew away vigorously for the next grazing. Lighter grazing provided the remedy and the cure.

The ill effects arising from over-grazing and under-grazing are easily prevented. The pasture must carry the right number of stock, not too many, not too few. There must be a source of food in reserve, a spare field or forage crop. Application of nitrogen, light harrowing, and, above all, rest, soon restore an over-grazed pasture. When, on the other hand, grass grows too fast and the number of stock is not sufficient to cope with the overgrowth the position may be met either by shutting up one or more of the fields for hay, or by using the mowing-machine to get rid of the surplus grass. The latter recommendation sounds unpractical until it is realized that it means no more than exchanging old clothes for new.

In short, as must always arise in working out the practical application of any new principles, all sorts of difficulties cropped up, but all of them proved how sweet are the uses of adversity by serving as starting-points for the discovery of ways of overcoming them.

It is certain that wherever the system is employed similar contretemps will arise. It is the business of scientific agriculturists to aid the farmer to surmount them. They are doing it, and examples of intensive grazing may be seen in this country at many of the Agricultural Research Stations and Institutions: the Cheshire School of Agriculture; Harper Adams College, Shropshire; the Hertfordshire Farm Institute; Seale Hayne Agricultural College; University Farm, Aberystwyth; Royal Agricultural College, Cirencester; at the experimental farm at Cockle Park, Northumberland, and others in England, Scotland, and Ireland.

The advantages of intensive grazing are clear; so are the disadvantages. To carry it out thoroughly a subdivision of fields is often necessary. The cost of fencing is not low. Water has to be laid on in each of the subdivided fields—often an expensive operation and in some places an impossible one. Nevertheless, as wide experience over six years shows, intensive grazing can be made a profitable part of farm practice. It may be adopted wholly or in part, and as will be shown presently, there are simple modifications of the system which give at all events many of the benefits obtained by the application of the system as a whole. Farmers themselves are engaged in working out these modifications. As a result of their efforts the system will become more elastic and variations fitting it more aptly to different branches of grass-land farming will be

devised. But even as it is, intensive grazing is a practice which no grass-land farmer can afford to ignore, for there is no other way in which food production can be increased so much or so profitably. At present, grazing land, except in comparatively rare cases, is treated in a haphazard manner. The vagaries of growth make the full utilization of grass impossible. Only by controlling them can grass be brought from the semi-wild condition in which it is now allowed to grow to a truly cultivated state.

A useful refinement of the system, due to Mr. Brunton, consists in giving preferential feeding to the heavy-yielding cows. He sends the heavy milkers ahead of the rest of the herd, giving them an hour or two in an as yet ungrazed field of young grass, thereby enabling them always to get the first clip. In this way the heavy milkers get rich food, get it quickly, lie down, rest, and make milk.

Strip grazing. Of all the simplifications which have been introduced, a semi-intensive system of grazing, the strip method, is perhaps the most important. Strip grazing saves the cost of fencing and watering each of the separate fields required by the full system.

The method may be illustrated by a concrete example. There are 20 cows to graze and there are two fields each of 9 acres set aside for them. One is dressed with fertilizers for early grass. One-third of the other, a strip at one end, is dressed a little later on and will, therefore, be ready about ten days after grazing began on the first field. So soon as the cattle have been taken off it a half or third of the first field is again dressed with nitrogen. The grass responds quickly. The cows find enough keep on the nitrogen and no-nitrogen parts of the second field until the first field is ready to be grazed again. The cows return

there and then another strip, or the whole of the remainder of the second field, is dressed with nitrogen. So, by careful attention to the times of application of nitrogen, there is always some young grass for grazing.

There is no need to wait till cows are off a field before dressing a part of it with nitrogen. The cows take a lick, leave it, and do not return for at least a week. Statements are sometimes made that the two nitrogen fertilizers commonly used, sulphate of ammonia and nitro-chalk, are apt to prove harmful if licked up by cattle or sheep. Investigation proves that the statements are without foundation.

The strip method has been tried on Mr. Maitland Mackie's farm at Aberdeen and on Mr. Iveson's farm in Yorkshire. Mr. Maitland Mackie has used a single large field the halves of which are dressed alternately. Mr. T. Iveson used three fields, part of each of which was strip dressed. In both cases the carrying capacity of the pastures was increased.

The alternative methods of intensive grazing offer ample opportunity for both the bold and cautious to apply one or other of them to their own grass land, and thereby contribute to the building up of systems suitable to all the varied conditions which occur in the grass lands of this country.

When all the methods are compared, however, there is no doubt that the full system is the best way of increasing the yield and at the same time improving the fertility of grass land.

The intensive system does not apply to cattle and sheep only. The pig-keeper can use it for the economical feeding of his stock. There are advantages in so doing.

Outdoor animals are healthier. Their rate of maturing can be delayed so that the animals are ready when, and not before, the market is ready for them. Experiments at Jealott's Hill have shown that sows thrive well and produce good litters when they are made to get so much as one-half of their daily food ration from grass. It has long been a practice among breeders to graze pigs on ordinary pasture. The advantage of grazing them on nitrogen grass is two-fold. The animals get a larger proportion of their food from the grass and a larger number of animals can be kept to the acre.

The young pig thrives on intensive grass and when grazed on it saves the pig-keeper from one-third to one-half of the food ration. The introduction to the grass diet must be gradual and the ordinary precautions for sheltering outdoor animals from undue exposure to sun or adverse weather must be taken.

THE ROTATION OF CROPS APPLIED TO GRASS LAND

The rotation of crops on arable land embodies the results of experience accumulated by observant and skilful farmers during the past three centuries. It has many advantages. A similar system, could it be applied to grass land, would also have many.

The good effects which result from the rotation of arable crops are well known. Rotation prevents the land from becoming sick of a crop and refusing to grow it. It gives opportunity for ridding the land of weeds which compete with crops for water and food. During the year or more under temporary grass included in the rotation, the land accumulates plant food for the benefit of the crops which follow after the grass is ploughed up.

The advantages of a rotation for grass land would be no less great. The production of food for stock would be spread more evenly over the year, and would do much to prevent the inconvenience and loss which now arise by reason of the excessive growth of grass at some times of the year and its poor growth at others.

The sheep farmer must have grass early in the year; the lambs have to be fed and therefore the flow of milk from the ewes must be maintained. So soon, therefore, as there is any grass to graze, the sheep graze it. They graze it bare. Each successive year the tender young grass is grazed before it has gained strength, and it is grazed down to the ground, with the result that the grasses of the pasture are impoverished. The clovers profit by the discomfiture of the grasses, and grow each year more luxuriantly. After the lapse of some years the pasture is predominantly a clover pasture. It can therefore produce but little early grass, nor can the clovers themselves make any contribution to the early bite which the sheep farmer so urgently requires. They are slow starters. Their growth is not encouraged by nitrogen, and although they give food in the middle of the summer, that is not the first requirement of the sheep farmer.

The farmer who specializes in producing milk is also eager to turn his cows out as early as the season will allow. If it is warm and not too wet, the cows are turned out to graze so soon as there is any grass for them to eat. It often happens that they graze the pasture bare and bring about a state of affairs similar to that in the sheep pasture. It becomes increasingly clovery and deficient in grass. The farmer may look with pride on the fields rich with wild white clover, but the permanent establishment of clover

over a large part of the grazings of the farm has many drawbacks. It is true that the clover provides an ample supply of feed in midsummer, when grasses are apt to be stemmy and therefore least nutritious. Nevertheless the clover season is a brief one, whereas that of the grasses can be made a long one. If, therefore, too much of the grass land on the farm is predominantly clover, there is but little keep early and late in the year when keep is just as precious.

It is but natural that the farmer should set great store by clovers. They have a high feeding value, satisfy their own nitrogen requirements, and produce food at the time of the year when the grasses are the least prolific. Furthermore the farmer has learned how easy it is to increase the clovers in pastures by the use of phosphatic fertilizers advocated so ably by the late Professor Sir William Somerville and the late Professor D. A. Gilchrist. But, as is always the case in life, no system, however good, is free from attendant disadvantages. The continued use of phosphates alone favours unduly the growth of clovers until the no less, or even more, important grasses are crowded out and at last the field becomes a clover field providing keep for stock for at best three or four months of the year.

Phosphates and nitrogen must unite their forces for the coming great improvement of grass land. Used together and accompanied by good management, they can ensure that on the grass lands of the farm there shall be clover fields, grass fields, and fields in which grasses and clovers are duly balanced.

The extremes to which the cultivation of clovers to the detriment of the grasses of a pasture have gone become picturesquely evident to the traveller who journeys from

Scarborough to Berwick in July or August, when the honey scent and snowy whiteness of clover in flower give an agreeable impression of luxuriant growth and prosperous farming. If, however, he make the same journey in April, he will find that there is on all those clover fields but the scantiest sign of growth. Yet if he steps out of his way to a small holding in Yorkshire where the use of nitrogen fertilizers is practised, he will find April fields green with grass and cattle grazing contentedly upon them. Or, if the northward journey is made yet earlier in the year he may turn off from Scarborough and inspect the farm cultivated by Mr. G. H. Hirst on the Wolds, some ten miles distant. There he sees, even though it be February, ewes already lambed or about to lamb which are getting more than half their food from grass. The gift of early grass, which fertilizers have bestowed, has resulted in a month's advance in lambing time.

There are times in the grazing year when management of pastures is difficult: the times of the natural flushes of growth in late spring and late summer. Grass grows away from the grazing animals. There is more grass than the stock can consume. The farmer has no means of stocking the land more heavily. In late summer the cattle are turned off the pastures and put to feed on the aftermath of the meadows. What the meadows gain, the pastures lose. The grasses of the pastures grow on unchecked. As the soil gets poorer and poorer in available nitrogen, the meaner grasses, the bents, uncontrolled by grazing, find occasion and space for intruding themselves. The better grasses are reduced; and the bents proclaim the deterioration of the pasture.

These examples compel the questions: is it inevitable

that farmers should look at grass land, as so many do, solely from the point of view of the stock on the farm? Must the pastures be sacrificed to the animals, both at times when grazing must be had at all costs and when grass must be left to grow unchecked! Can the new knowledge of grass land be used to frame answers to these questions? It seems that it may.

A system of rotational cropping of grass land, if it proved practicable, would give the final answer. Therefore a rough sketch will be made showing how, with all due caution, the farmer might build up gradually a system which would do in some measure for grass land what rotation of crops does for arable.

Consider, for example, the farm carrying mixed stock and containing a fair proportion of grass land in which clovers and grasses flourish. The occupier, a progressive man, has already learned the advantage of early grass. Long before winter is over he selects the early bite fields for next year; he either applies a dressing of phosphate and potash late in the winter and a dressing of nitrogen in February or March, or else a complete fertilizer in early spring. Throughout the whole rotation he will make sure that there shall be no lack of growth due to any shortage of the essential plant foods. Late in March or April, if the season proves to be a normal one, the early bite fields are ready for grazing.

First year of the rotation—the early bite field. After the early bite the fields are grazed hard throughout the season and give good autumn keep. The grass is needed; and, moreover, the hard grazing begins to check the grass and gives opportunity for the clover to reassert itself.

Second year—the early semi-bite field. The early bite field

of the year before is just as early, but because of the hard grazing which it had then the amount of grass is no more than one-half of what it was a year ago. It is again grazed hard and in consequence the grasses are so punished that by midsummer the field in which eighteen months ago grasses predominated is become a clover field, giving good grazing in July and August, but little autumn keep.

Third year—the clover year. Clovers predominate. The attenuated grasses give so little grazing that there is none to be had before the beginning of May or even later. There is plenty of summer feed from the clovers, but the fields are not grazed hard and, as a result, the grasses reassert themselves and give good autumn grazing.

Fourth year—the hay year. No grazing in spring in order that the grasses may make good growth. The field has to serve two purposes—to yield a heavy hay crop and, by the luxuriant growth of grass, to bring the clovers into subordination. Provided there be no lack of plant food, the aftermath gives good grazing when the hay crop has been taken, and that at a time up to the end of August when grazing is most precious. When August is past, the field is rested. The established grasses gather strength. Full of the vigour which reserves of strength give, they are quick to awaken in the spring and yield the early bite in the following year, the first of the next rotation.

All these changes, the comings and goings of grasses and clovers, have been brought about by Mr. Martin Jones at Jealott's Hill. His experiments were made on a young pasture sown down two years before. It must be conceded at once that there is no evidence that the changes can be brought about with equal ease on a long-established pasture. The general opinion is that they cannot, but

experiment has the last voice in all these things and it is part of the programme of Jealott's Hill to discover whether or not old pasture will respond as submissively as young. It may be that the long-established grass will exhibit the prerogative of age and prove more averse from change than the young, but even though analogy suggests that the old grasses may be slow, it also promises that they will be sure: and that clovers and grasses of the pasture long established will come gradually to respond in the same way as they do in the more youthful pasture.

The experimental plots at Jealott's Hill show how strong is the growth of grasses rested after August grazing. The grass seized its chance during the hay crop, and dominated the clovers. The autumn rest aids its re-establishment by giving grass the chance to lay up stores of food before the winter and, therefore, it is in the best possible condition to provide a plentiful early bite in the ensuing spring.

The heavy grazing throughout the early bite year serves two purposes. In the early part of the year it depresses the grasses and helps the clovers; the later heavy grazing serves to keep out the bents, those enemies of good pastures, and so the next year sees the clovers in possession. Their predominance, however, must not be left long without dispute. The pastures are lightly grazed. The grasses find their opportunity, and as the year goes on they wax as the clovers wane. The field is ready to give a good hay crop in the next year.

All these controlled and gradual changes, this swaying to and fro of the conflict between the grasses and the clovers, have been brought about by the use of fertilizers and the adjustment of grazing to predestined ends.

The alternative domination of a pasture now by grasses,

now by clovers, can be achieved in those parts of the country where fairly heavy soil and good rainfall divide their favours evenly between grass and clover. Whether the changes can be brought about so easily in districts which favour one more than the other or in those which give encouragement to neither remains to be proved.

Other lines of investigation, however, and particularly the brilliant work carried out by Professor Stapledon and his colleagues at Aberystwyth, are providing new forces to help the farmer in the improvement of his grass land. It has been shown, for example, that each kind of grass may exist in several distinct forms or strains; some are strong, some weak, some are wellnigh everlasting, some more ephemeral. There are strains of this or that kind of grass which are good pasture plants, there are others which are more fitted for life in meadows; there are other strains which are bad for both.

Improvement of existing strains of the several kinds of grasses and clovers of a pasture may also play a large part in finding for a rotation of grass-land crops a place as prominent in the practice of the grazier as that held by the rotation of arable crops in plough-land practice.

IX

FERTILIZERS ON THE ARABLE FARM

Fertilizers throughout the rotation. Roots. Spring corn. Seeds ley. Wheat. Fertilizer balance sheet. Financial returns. The fertilizers used for arable crops.

FERTILIZERS used to increase food production cannot bring a full profit to the farmer unless they are applied in the right way. To learn all that is known about the effects of fertilizers on crop production and soil fertility is the work of a lifetime; but to find out how to apply proved knowledge needs but little time or trouble. It is true that soils differ widely from one another. Some are hungry for all the plant foods; they are many. Some contain enough for the production of an average crop, but not enough to yield bountifully: they are still more numerous. Some are rich in all the plant foods; but they are very rare. Scarcely any soils contain enough phosphates to provide for the needs of a crop. Nearly all the soils of the world are famishing for phosphates.

The deep black soils of the fen country and elsewhere tell by their colour that they hold rich stores of nitrogen, but, as will be shown presently, the stores, although great, are not always released quickly enough to satisfy the large requirements of a crop in its young stage. Soils of other colour are almost invariably insufficiently endowed with nitrogen and must therefore receive not now and then but at regular intervals additions to their meagre store.

Heavy clay soils often contain a sufficiency of potash, but the lighter soils are generally deficient in this essential plant food. The farmer can easily find out whether his land is well or ill supplied with potash. If it bears heavy

crops of mangolds and sugar beet, the leaves of which never show brown streaks or patches; if the crops stand up well in times of drought, and if the potato crop is consistently above the average and keeps green well into the autumn, the farmer may be sure that there is plenty of potash in the soil. To make certain he can consult the County Agricultural Organizer, who will generally be able to tell him straight away, and the farmer can, at the same time, ascertain whether the soil is well supplied with lime.

These things done, the way to the right use of fertilizers is easy.

Fertilizers throughout the rotation. The farmer is beginning another course in the rotation which he practises. He follows the four-course rotation, as is the case frequently in England. What kinds and amounts of fertilizers should be applied to each crop, and what will be the requirements of the land for plant foods when the rotation has come to an end?

The farm has been found to require potash, and the none too large yields which it has been giving are evidence that it must have phosphates and nitrogen as well. This being the case, applications of a complete fertilizer must be made from time to time in the course of the rotation.

A complete fertilizer contains all the three plant foods. It may be applied in one of three different ways. The farmer can use the appropriate concentrated complete fertilizer, the corresponding amount of a suitable kind of one of the more bulky mixtures, or he can buy the ingredients separately and mix them for himself. Concentrated complete fertilizers are made in granular form. Owing to their concentration the same amounts of nitrogen and mineral fertilizers are contained in about one-half the bulk

of the ordinary mixtures, thus saving transport and lightening the work of spreading the fertilizers on the land. The mixed fertilizers, on the other hand, generally contain gypsum in addition to nitrogen, phosphates, and potash. This compound of lime acts beneficially on some of the heavy soils and also on light soils, and, therefore, in cases of soils which are very deficient in lime the gypsum gives the mixture some advantage over the concentrated fertilizer. The farm, however, on which the rotation is to be followed has been supplied with lime, and therefore the farmer is free to make his choice between them.

Experiments carried out at Jealott's Hill comparing the effects of the two kinds of fertilizer show that on land which is not deficient in lime the concentrated fertilizers and the mixtures have equal effects in increasing crop production.

Whichever kind of fertilizer is used, the farmer must see to it that it is distributed evenly over the ground and in the right amount. Broadcasting by an experienced man may be as effective as spreading by a fertilizer distributor, but in the hands of the unskillful broadcasting is wasteful. On the other hand, not all the fertilizer distributors on the market are good. A good distributor is one which when set to deliver, say, 2 cwt. to the acre, spreads that amount, no more and no less, and delivers it uniformly. Tests of the chief makes of distributor carried out at Jealott's Hill in 1930 prove that there are wide differences in efficiency between the different makes. The results, published in the *Journal of the Ministry of Agriculture*, have been valuable in that they have led already to improvements in manufacture.

Like all farm operations, the purchase no less than the

distribution of fertilizers should be made at the right time. The requirements of the land must be estimated in advance, so that the fertilizers are delivered well before they have to be used. The same forethought which leads to the timely order will also make sure that the fertilizers, when they arrive, are placed in a weather-proof store: for, although great care is taken by manufacturers to produce fertilizers which do not cake, neglect of proper storage with the consequent exposure to weather may cause the fertilizer to set in hard lumps. Common sense will also insist that the fertilizers are spread so far as possible during still and dry weather.

So much for generalities: now to the farm.

Roots. The rotation begins with roots which follow wheat, the last crop of the previous rotation. Every good farmer puts on the land which is to carry mangolds or a similar root crop as much farmyard manure as he can spare—10 or 15 tons are spread during the winter or early spring. Having done this, the farmer may suppose that he has done all that is necessary to supply the crop with plant food. He has not. The virtues and peculiarities of farmyard manure are described later on, but it must be stated here that although farmyard manure contains all the plant foods, it does not contain them in suitable proportions. Farmyard manure does not provide a balanced food for plants. Nor, unless the amount used is large, are the quantities of the plant foods which it contains sufficient to supply a growing crop with food as fast as it needs it. The farmyard manure which has been applied contains plenty of nitrogen, but its nitrogen is paid out slowly, and in the spring of the year, when the crop most needs it, the manure is giving nitrogen too grudgingly. Later in the

year, when the plant wants but little, the nitrogen continues to be dribbled out, so that much is wasted.

Moreover the 10–15 tons of farmyard manure applied to the roots do not contain enough phosphates or potash to serve for high crop production.

The conclusion must not be drawn from these facts that the use of farmyard manure should be given up. Far from it. It will be shown presently that farmyard manure does to the soil many beneficial things which fertilizers cannot do, and the good farmer will go on using as much of it as he can get. The right conclusion to be drawn from the facts is that unless farmyard manure is supplemented by both nitrogen and mineral plant foods, it is used wastefully. Therefore, notwithstanding the fact that a dressing of dung was given, the land to be put under roots is supplied with a complete fertilizer just before planting time.

The composition and quantities of the fertilizers used on each of the crops in the rotation are given all together later on in this chapter, but in following out the rotation it will be sufficient to state in terms of their essential ingredients (nitrogen, phosphoric acid, and potash) the quantities of each of the plant foods which are applied to the crops.

The mangold or sugar beet receives a good dressing containing to the acre:

> Nitrogen, 70 lb. Phosphoric acid, 70 lb. Potash, 120 lb.

If swedes are grown as well as mangolds, they get:

> Nitrogen, 25 lb. Phosphoric acid, 115 lb. Potash, 50 lb.

Potatoes are also grown as a part of this course of the

rotation. The potato gives a good crop even without the aid of dung. The complete fertilizer which suffices when, as in the present case, dung is used contains to the acre:

Nitrogen, 70 lb. Phosphoric acid, 70 lb. Potash, 140 lb.

Quantities of fertilizer much in excess of these amounts are often given by skilled potato growers, but the amounts prescribed will in an average season ensure a crop of not less than 8 tons to the acre: nearly 2 tons above the average.

It may well be, however, that the yield which the farmer gets is in excess of this amount—a cause for thankfulness and a tribute to good cultivation. Let him not think, however, because the fertilizer gave such good results that he can double or treble them by using double or treble the amounts. If he is wise he will either leave well alone or make haste slowly by trying out on a small acreage the effects of a further increase of fertilizers. The larger amount will certainly supply more food, but weather and the state of the soil and so forth may prevent the extra amount of fertilizer from producing its full effect, and in that case the additional cost may not be met by the increased crop.

Or the farmer may not get the increase of 2 tons predicted for the potato crop. Let him not, however, blame the fertilizer, but use the disappointing result as an indication that all is not well with his methods. The potatoes may have been planted too late. The variety planted may be unsuitable to the district. Disease may take heavy toll of the crop. Cultivation of the land, in itself one of the best manures, may have been insufficient. The hoeing or earthing-up may have been delayed, with the result that weeds grew and appropriated to themselves much of the

fertilizer destined for the crop. Therefore he will not be deterred by a failure, but will determine to get on his own farm the same results which are already being got on thousands of others.

The root crop is not ready for lifting until autumn is passing. The land must therefore wait till late autumn or winter before it can be prepared for spring sowing. Needless to say, the farmer on heavy land seizes the first propitious moment for ploughing, because winter exposure does much to improve the soil and make spring work lighter.

Spring corn. The second year of the rotation sees the sowing of oats or barley in March, and when the corn is up clover seed or a mixture of grass and clover seeds is drilled or broadcast among the corn in order to provide temporary grass in the third year of the rotation. Most farmers give no fertilizer to the spring corn crop. They rely on the residues left over from the preceding crop, but if the crop has been as large as it should be, the residues of plant food left in the soil are meagre, and the wastage which goes on in the winter reduces yet further the amounts which are available to the succeeding crop.

Supplies of plant food must be replenished, and this is especially true of nitrogen plant food, for although a liberal dressing of farmyard manure was given to the root crop of the preceding year, much has been lost or has become locked up in the soil.

Fertilizers, and particularly a nitrogen fertilizer, must be applied to secure a good yield of the oats or barley and a good stand of the temporary grasses which are to occupy the ground after the corn crop has been harvested. Large quantities of nitrogen fertilizer are, however, not applied at this stage; for if they were, the oats or barley might grow

so strongly that the seeds of the grasses and clovers would make but weak growth, overshadowed as they would be by the strong-growing straw of the cereal crop.

There is also another reason why the spring-sown corn crop must not be over-fed. The larger the crop, the greater its demand on the water of the soil. If the season is a dry one, and a well-fed oat crop is taking up large quantities of water, the grasses and clovers, which in any circumstances are not enjoying ideal conditions, fail to take satisfactorily. Nevertheless, the practice of withholding fertilizers from the spring-sown corn crop should be abandoned. The corn should be dressed with a complete fertilizer containing a relatively small amount of readily available nitrogen, a larger amount of phosphates and, where the soil requires it, a due proportion of potash. Potash in particular is necessary. It is a form of insurance against dull summer weather, for, as Rothamsted has shown, plants growing in a sunless season are much benefitted by it; and in any year the clover and grass seedlings beneath the corn have to grow in sunless conditions. The fertilizer which is applied contains to the acre:

> Nitrogen, 23 lb. Phosphoric acid, 46 lb. Potash, 23 lb.

Seeds ley. Presently the oats or barley is reaped. The grasses and clovers already established begin to make autumn growth. The former may be encouraged by a light dressing of nitrogen. By this means it is often possible to get useful grazing in the late autumn of the year in which the grass was sown.

The common idea that plants give up active growth in autumn because of the inclemency of the weather is only

half true. They give up growth for two reasons: bad weather and partial starvation. If there is enough plant food in the soil nothing but weather of extreme severity stops their activities. Late autumn grazings induced by dressings of nitrogen have been obtained on the bleak wolds of Yorkshire. There in the wolds temporary grass in its first year is being used to supply grazing sheep with food so late as November, and the effect of the fertilizer is evident, not only in the autumn, but in the following spring. Supplied with a sufficiency of nitrogen food, temporary grass is so quickened into growth in spring that sheep are grazing it in February. Where a late autumn bite of the temporary grass in the first year is not required, the dressing of nitrogen should be delayed until the early spring in order to secure a heavy yield of hay from the temporary grass and clover ley. Furthermore, if a good second crop is wanted for hay or grazing, a second dressing of nitrogen should be given after the hay has been cut.

Wheat. The rotation is at the end of its third year: the temporary ley is ploughed up, and the organic substances assembled in the roots of the plants are, by their decay, made available for the next year's crop. The farmer sows wheat in autumn, and, confident that the ground has been enriched by the temporary pasture, only too frequently sows it without the addition of a fertilizer. The farm under the rotation is of but average fertility and, therefore, unlike some which need nitrogen only for the wheat crop, it must be supplied with all the three essential plant foods. The mineral fertilizers are given after the land has been ploughed up and is ready for the sowing of the corn.

Here the farmer may object and say that he has seen bad effects follow from the use of nitrogen fertilizer on the

wheat crop. The corn lodged, with the result that much of the grain was lost and the trouble of reaping greatly increased. The objection is considered carefully later on, but here it only need be said that unless the farmer does give a dressing of nitrogen in the spring, his land, none too well supplied with this plant food, will not produce a heavy crop. Therefore, although perhaps with reluctance, he follows the advice and adopts the practice which, as will be shown presently, experiments carried out at Jealott's Hill suggest to be the best, namely, he adds the nitrogen in accordance with the condition of his crop. If it is looking yellow in the spring with broken ranks, he gives one-half the dressing as soon as possible in early spring. If the crop has come well through the winter, he waits until growth is under way and then gives the full dressing of 2 cwt. of nitrogen fertilizer to the acre. If the half was given early, the other half is given now.

Nitrogen (early spring), 23 lb.; (late spring), 23 lb.
Phosphoric acid, 46 lb. Potash, 23 lb.

In Berkshire, on fairly heavy land, the best time of application has been found to be about the middle of May, and it has also been found that when the application is made then, somewhat later than is customary among farmers, the grain is benefited rather than the straw, whereas when the nitrogen is applied early in spring, as it usually is, the fertilizer may have the opposite effect.

The rotation is at an end.

Fertilizer balance sheet. The balance sheet of the supply of the fertilizers, given in full in Appendix XII, shows that the pounds per acre of the different fertilizers used during the rotation are:

Nitrogen, 301 lb. Phosphoric acid, 219 lb. Potash, 334 lb.

It might be supposed that these quantities would have served to build up large reserves of plant food in the soil. It is not so. The crops of the rotation have been larger than the average, only because they have had access to and have used large quantities of plant food. They have taken from the land in pounds per acre:

Nitrogen, 319 lb. Phosphoric acid, 115 lb. Potash, 383 lb.

With respect to nitrogen, the land is no better off than it was at the beginning of the rotation, and supplies must be provided for the next. It looks as though phosphates had been given too liberally. They have not. It is true that one-half of the phosphates supplied is left behind, but phosphates have the habit of getting locked up in the soil or disappearing beyond the reach of the plant. Therefore the farmer, if he places reliance on the imaginary store of surplus phosphates, will be doomed to disappointment. All the potash added as fertilizer has gone into the plant and, as the figures show, the soil has been called upon to yield up some of its reserves to supplement the potash of the fertilizer.

The work of the rotation is finished, but the supply of fertilizers to the soil is never finished; and in the next rotation the same liberality in providing plant food must be bestowed as was exercised in the one which has been described.

The plant food contained in the farmyard manure which was supplied to the root crop is taken into account in drawing up the balance sheet, but the amount of nitrogen

supplied in the temporary ley is not. It may have amounted to 21 lb. to the acre (see p. 178); but even so the quantity of nitrogen supplied to the land is to all intents and purposes only just equal to that which the growing crop took out of it. When, indeed, allowance is made for the incessant wastage of nitrogen in the soil, particularly by the washing out of nitrogen by rain, there is no doubt that the stores of this essential plant food are actually less than they were at the beginning of the rotation. The fertilizers have succeeded in all but maintaining the fertility of the soil. Had they not been given, the farm would have presented the spectacle only too frequently to be seen at the present day of land undergoing a steadily progressive decline in fertility.

Financial returns. Any one interested in the greatest of all national problems, the re-establishment of agriculture, who has followed the account of the effects which fertilizers produce on crop production throughout the rotation carried on on an ordinary farm, will be bound to ask the questions: what have the fertilizers cost, and what profits have their use brought to the farm? It is easy to give a direct answer to the first and impossible to give a direct answer to the second question.

The cost of fertilizers used in the rotation is readily calculated. The fertilizers used throughout the rotation contain (see Appendix XII):

Nitrogen, 170 lb. Phosphoric acid, 177 lb. Potash, 153 lb.

The cost of 1 lb. of each of these fertilizers is:

Nitrogen, 3·66 pence. Phosphoric acid, 1·96 pence. Potash, 2·32 pence.

From these figures it is possible to calculate exactly what the fertilizers which he uses cost the farmer.

It amounts to £1 7*s.* 7*d.* per acre per annum.

No such simple calculation will provide an answer to the second question: what profits do the fertilizers bring? Prices of farm produce fluctuate. The areas which are given to the different root crops vary considerably in different parts of the country. Some of the arable produce is sold, other of it is used on the farm for feeding live stock. Costs of production—labour, rent, situation, the layout of the farm making operations cheap or costly, type of soil, whether heavy or light—all affect costs of production so much that to strike an average for the country as a whole is impossible.

There is, however, one way by which a fair indication may be gained of the difference between the value of the increased crop and the cost of fertilizers which produce it.

Among the experiments carried out at Jealott's Hill those relating to the several crops of the rotation show the increases of yield which are obtained when fertilizers are used in a manner almost identical with that adopted in the rotation. The increases are shown in Table XVII.

In order to obtain figures for the prices realized by the several crops, the prices current in 1931 have been taken. All these prices are low. Wheat, for example, sold for £5 15*s.* per ton, a price which even in the most favourable cases could leave but little if any profit to the farmer. To ensure that there should be no suspicion of using favourable prices, the potato crop is estimated in terms of 1930 prices. In that year the potatoes, when he could sell them, brought the farmer so low a price as £3 12*s.* per ton, whereas in the following year the price was well over £5. For the

Table XVII

Returns from Fertilizers used on the crops of the Four-course Rotation

	Crop	Increase of yield per acre	Price realized	Value of increase per acre		Cost of fertilizers per acre		Differences between value of increased crop and cost of fertilizers	
			£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
	Potato	4 tons	3 12 0 per ton (1930) price	14 8 0	..	2 13 3	..	11 14 9	..
	Sugar beet	3·3 „	2 3 0 „ (1931) „	7 2 0	..	1 19 1	..	5 2 11	..
	Mangold	11·0 „	9 0 „ feeding value 1931	4 19 0	..	2 12 2	..	2 6 10	..
The Root Year	..	..	.. ..	..	8 16 4	..	2 8 2	..	6 8 2
	Oats	4·6 cwt.	7 10 0 per ton (1931)	1 14 6	..	19 0	..	15 6	..
	Barley	4·4 „	6 10 0 „ „	1 8 7	..	16 2	..	12 5	..
Spring Corn Year	..	..	.. ..	..	1 11 6	..	17 7	..	13 11
Seed Hay Year		12·4 cwt.	2 5 0 per ton feeding value 1931	..	1 7 11	..	7 0	..	1 0 11
Wheat Year		6·3 cwt.	5 15 0 per ton (1931)	..	1 16 3	..	1 12 2	..	4 1
For the 4 Years of the Rotation:					13 12 0	..	5 4 11	..	8 7 1
For One Year:					3 8 0	..	1 6 3	..	2 1 9

same reason allowances are made neither for increased yield of straw in the corn crops, which amounts to from 5 to 10 cwt. per acre, nor of the value as food of the increased quantity of sugar-beet tops (1 ton to the acre) produced by the fertilizers. Neither is any allowance made for the residual values of the phosphates and potash contained in the fertilizer. In order to estimate the value of the man-golds and seeds hay crops which are used for feeding live stock, the official figures published by the Ministry of Agriculture for November 1931 have been taken.

	£	*s.*	*d.*	
The results of the estimate is that the cost of fertilizers throughout the four years of the rotation is:	5	4	11	per acre
The value of the increased production:	13	12	0	”
Therefore the yearly averages are:				
Cost of fertilizers[1]	1	6	3	”
Value of the increased production:	3	8	0	”
That is to say, the difference between the value of the increased crop and the cost of fertilizers is:				

This figure makes no allowance for the cost of distribution and freight of the fertilizers, nor is there any need to include this cost, which amounts to a sum ranging from 3*s.* to 5*s.* per acre. For the figures must be discounted by a much larger amount, and this for numerous reasons, the chief among which is the fact that the yields on experimental plots almost invariably turn out to be higher than those obtained over large areas. How much the discount

[1] The Jealott's Hill crops received approximately but not absolutely the same quantity of fertilizers in the four-course rotation, hence the difference between this figure and £1 7*s.* 7*d.* given on page 137.

should be must remain a matter of opinion. On the one hand, there is the generally higher yield obtained on small plots; on the other, there are the results of the Recorded Farms set forth in Table V, p. 28, which show how close is the correspondence between the increased yields obtained on upwards of 2,000 acres of farmland and those given by the experimental plots at Jealott's Hill.

Taking everything into consideration, it would seem fair to discount the figures by one-third (33 per cent.). When this is done the difference between the increased value of the crop and the cost of fertilizers amounts to 19*s.* 1*d.* per acre: a return of 73 per cent. on the outlay on fertilizers.

Prices are the master of the situation. The 73 per cent. return may, in present conditions, mean a handsome profit to the farmer. It may mean nothing of the kind. In spite of his enterprise he may still make a loss. At all events, and at the worst, it can be said that any loss which he incurs will be less than it would have been if he had re-acted to the hard times through which he has been going by cutting down expenditure and putting up with poor crops.

Therefore the final conclusion is that the farmer who strives to increase food production and brings fertilizers to his aid in doing it will not only benefit the nation but also derive advantage for himself: unless the lean kine of prices devour the fat kine of production, and the farmer is destroyed altogether.

THE FERTILIZERS USED FOR ARABLE CROPS

Each of the crops of the four-course rotation is grown every year on part of the arable land of the farm. The balance sheet given in Appendix XII is based on the average areas occupied by each of the crops in any one year. Some fields are under roots; some are growing spring corn; others are under temporary ley, and yet others carry winter wheat. Each crop receives its own proper ration of fertilizer and each ration is varied according to the nature of the soil.

The following examples of the fertilizers which should be applied to each of the crops represent averages and would have to be modified in special cases.

Mangolds and Sugar Beet

Average plant food to be supplied per acre in artificial fertilizers: Nitrogen, 70 lb.; Phosphoric acid (P_2O_5), 70 lb.; Potash (K_2O), 120 lb.

On heavy soils with a light dressing of dung:

Sulphate of ammonia	3 cwt.	or 5 cwt. of a corresponding concentrated complete fertilizer.
Superphosphate (14 per cent.)	4½ ,,	
Muriate of potash	1½ ,,	
or Potash manure salts (30 per cent.)	2½ ,,	

On light soils with a light dressing of dung:

Sulphate of ammonia	3 cwt.	or 6 cwt. of a corresponding concentrated complete fertilizer.
Superphosphate (14 per cent.)	4½ ,,	
Muriate of potash	2½ ,,	
or Potash manure salts (30 per cent.)	4 ,,	

Swedes

Average plant food to be supplied per acre in artificial fertilizers: Nitrogen, 25 lb.; Phosphoric acid (P_2O_5), 115 lb.; Potash (K_2O), 50 lb.

On medium to heavy soils with a light dressing of dung:

Sulphate of ammonia	1 cwt.	or 3 cwt. of a corresponding concentrated complete fertilizer.
Superphosphate (14 per cent.)	5½ ,,	
Ground mineral phosphate	¾ ,,	
Muriate of potash	½ ,,	
or Potash manure salts (30 per cent.)	1 ,,	

On chalk soils with a light dressing of dung:

Sulphate of ammonia	1½ cwt.	or 4 cwt. of a corresponding concentrated complete fertilizer.
Superphosphate (14 per cent.)	6½	
Ground mineral phosphate	½	
Muriate of potash	1	
or Potash manure salts (30 per cent.)	1¾	

POTATOES

Average plant food to be supplied per acre in artificial fertilizers: Nitrogen, 70 lb.; Phosphoric acid (P_2O_5), 70 lb.; Potash (K_2O) 140 lb.; applied as:

Sulphate of ammonia	3 cwt.	or 6 cwt. of a corresponding concentrated complete fertilizer.
Superphosphate (14 per cent.)	4 ,,	
Muriate or sulphate of potash	2½ ,,	

With a light dressing of dung.

BARLEY OR OATS (SPRING SOWN)

Average plant food to be supplied per acre in artificial fertilizers: Nitrogen, 23 lb.; Phosphoric acid (P_2O_5), 46 lb.; Potash (K_2O), 23 lb.; applied as:

Sulphate of ammonia	1 cwt.	or 2 cwt. of a corresponding concentrated complete fertilizer.
Superphosphate (14 per cent.)	3 ,,	
Muriate of potash	½ ,,	
or Kainit (20 per cent.)	1 ,,	

SEEDS MIXTURES

Average plant food to be supplied per acre in artificial fertilizers: Nitrogen, 23 lb.; applied as:

Sulphate of ammonia	1 cwt.

WHEAT (AUTUMN SOWN)

Average plant food to be supplied per acre in artificial fertilizers: Nitrogen, 46 lb.; Phosphoric acid (P_2O_5), 46 lb.; Potash (K_2O), 23 lb.; applied as:

Sulphate of ammonia	2 cwt.*	or 2 cwt. of a concentrated complete fertilizer in early spring followed by a top-dressing of 1 cwt. sulphate of ammonia or 1½ cwt. nitro-chalk.
Superphosphate (14 per cent.)	3 ,,	
Muriate of potash	½ ,,	
or Kainit (20 per cent.)	1 ,,	

* Applied in spring as one or two top-dressings.

X

SOIL FERTILITY: THE SCIENTIFIC USE OF FERTILIZERS

Drainage. Liming. Greedy crops. Balanced rations of food for plants. Nitrogen thrifty crops. Crop predilections. Farmyard manure. The soil bank. Response of varieties to nitrogen.

SOIL FERTILITY

THE causes which make a soil fertile or infertile are many and various. Some of them are known: others are only beginning to be understood.

The soils which Nature makes are built, some of poor materials—sands or gravels—and some of more promising materials, the clays for example. The raw materials of soil, no sooner are they laid down than they begin to be worked upon by Nature's agents—air, rain, sun, wind, and microscopic, as well as visible, plants and animals.

The physical agents act both as creators and destroyers of soil fertility. By disintegrating the raw material they bring it to a state in which crops can grow. By washing out and dissolving away the plant foods they rob it of fertility. Some of the materials out of which soils are made are well endowed with plant food; the limestone rocks rich in phosphates and the clays full of potash are examples. Others, such as the sandy soils, are naturally poor in food substances.

The vital agents also help both to make and mar the fertility of a soil. Some construct, others destroy. Soil is a living thing. All but the most barren of soils contain a teeming population of micro-organisms. The discovery of all the causes which lead to soil fertility and soil infertility will not be made unless there is ever constant in the mind

of those who seek it the fact that the fertile soil under a crop is the battle-ground of armies always contending against Nature, and often contending among themselves. They are the multitudinous plants of the crop and the infinitely more multitudinous microscopic forms of life which live in the soil. The commissariat which feeds the armies is hard put to it to provide the water and the nitrogen and mineral food for their feeding: water may give out and always, or almost always, there is a shortage of food supplies: hence the contention! Crop plant competes with crop plant, and the invisible armies of soil bacteria compete with the crop and with one another for food, the supplies of which are not only insufficient but vary in amount and kind from month to month, from day to day, and even from hour to hour.

The microscopic flora and fauna of the soil are the arbiters which decide what the crop may have, and this they do in two ways. Living, they take their full share of the foods which the crop also requires, and therefore, unless the supplies are very plentiful, the crop must needs go short and that often at times when it wants them most. In this mood they are the enemies of the plant; but they are also its greatest benefactors. Some of the soil bacteria make out of raw material, unsuitable in its unchanged state, food substances which they share with the plant. And even those which in their life are no friends of crops bequeath to them at death the rich accumulations of food which they hoarded up during their lives.

The secrets of soil fertility will be revealed only when the ways of life of the many kinds of the bacteria and other microscopic organisms of the soil are known. Crops, soil, and soil micro-organisms must need be investigated

simultaneously: a great task fraught with great issues for the welfare of mankind.

For this reason soil science will have to submit to the same rebuilding which the sciences of chemistry and physics have undergone during the last twenty years and are still undergoing every day.

A soil at the time of its formation may contain no nitrogen food. Soil bacteria invade it, take nitrogen from the air, weave it into the fabric of their bodies, increase and multiply, win more and more nitrogen from the air, and, dying and decomposing, bequeath as a legacy to the land they live in nitrogen food for subsequent generations of plants. Without the aid of bacteria the soil is condemned to relative infertility until such time as the science of man intervenes to supply the omissions of Nature.

When all the natural agents, both physical and vital, have played their part, the soils of the world show all degrees of fertility; barren sand, water-logged swamp, sullen clay, limeless soils up to those rare natural oases which enjoy to the full all the conditions and materials which make for soil fertility. In this patchwork the farmer has to carry on the work of cultivation, and the art of the cultivator consists in bringing all these soils, or such of them as are in any degree responsive, to an increasingly higher level of fertility.

There are parts of the world in which the farmer attempts to do nothing of the kind. He takes and exploits the bounty of Nature, grows crop after crop with the minimum of cultivation, robs the soil of its capital, until at last, leaving it derelict and overrun with weeds, he moves on to devastate agriculturally another tract of land.

There are other parts of the world, these islands for

example, where the exploitation of the present to the ruin of the future is not practised. The British farmer is a cultivator in the true sense of the word, and the history of farming in this country shows that whenever he has had the means he has carried out punctiliously all those operations which help to maintain or increase the fertility of the land.

Drainage. Foremost among these operations is drainage. Much of the land in this country consists of heavy clays. They have great inherent fertility; but it can only become operative when the clays are brought into and kept in a state congenial to the growth of plants.

Unless they are drained, the clays remain infertile. Roots growing in their dense, compact mass can find no air, and rot. Nor can they find warmth, so cold are these soils by reason of the water they retain. Drainage, cultivation, liberal applications of farmyard manure must all be used to bring out and make active the latent fertility of these soils.

For permanent improvement, drainage is the first requirement. By getting rid of surplus water, air is let into the soil, the roots of plants can live in it, and the soil bacteria can begin their constructive work, alternately storing and yielding up food, and all the time changing the materials needful to the crop.

Cultivation follows on. Early autumn ploughing lays up the soil, exposing it to the disintegrating action of wind and frost and thereby making a good tilth. The soil begins to be fertile. But when the farmer, used to doing these things, finds himself impoverished, some have to be left undone. The first is drainage: ditches go uncleaned, drainage outlets become choked and their position

forgotten. Gradually with the lapse of time, the very fact that the land was ever drained passes out of memory. All that the farmer can do now is to carry on an unequal struggle against the forces of Nature. By paying close attention to surface cultivation, he is still able to secure a fair yield, in spite of the fact that the generous depth of earth, so necessary for bountiful production, is now replaced by a shallow soil which can yield but grudgingly.

If farmers of heavy land had the leisure to explore beneath their feet, they would discover often elaborate systems of drainage laid down long ago and long since passed out of operation. There may have been mistakes in laying the drains. The pipes perhaps were too small and too deeply laid; but economic stress has led gradually to failure to maintain the drainage. Imperceptibly year by year the operations necessary for its maintenance have had to be forgone; so that gradually all the old system, which once no doubt worked well, has ceased to work at all. Discoveries of old and elaborate drainage systems have been made on the farm at Jealott's Hill and could doubtless be made on many other farms in similar situations.

Long years of neglect to maintain drainage have led to serious deterioration of the soil. It becomes so waterlogged in winter that crops are slow to start in spring. The land, with its perennial youth, renews its fertility every year, but every winter sees it slipping back again. The winter-sown corn has, in wet years, a sickly look with many gaps in the rows, spring sowing and planting are delayed, and farm operations are made doubly laborious.

Much of the land of Great Britain calls aloud for drainage. The areas which could be dealt with most easily are those which have been drained in the past but in

which, for the reasons given, the drainage systems have become progressively less effective.

The cost of renovation is generally beyond the resources of the individual farmer or landowner. The prices which the farmer is accustomed to receive for his produce make it impossible for him to incur the expense.

The Agricultural Output of England and Wales, 1925,[1] confirms statistically these conclusions. 'Over a million acres of agricultural land in England and Wales are urgently in need of drainage and another half million acres are capable of improvement by drainage.'

Land imperfectly drained responds more grudgingly to fertilizers than does well-drained land. Were all the land which needs it to be supplied with drainage, the food production of these islands would be increased by an amount largely in excess of the estimates given in Chapter VI.

Liming. There is another cause which contributes year by year to soil infertility, and one, moreover, which operates not only on the heavy clays but also on the lighter soils. It is the spiriting away by Nature of such gifts of lime as have been bestowed on the soil either by Nature herself or by the farmer.

Lime is no less a plant food than are nitrogen, phosphates, and potash. Like them, lime is both a plant food and a soil food. It increases the fertility of both. When supplies of lime fall below a minimum crops suffer. So also do those bacteria which help directly to provide the crop with food. They become more and more idle in their work of improving soil fertility. The soil deteriorates.

[1] *The Agricultural Output of England and Wales*, 1925. Ministry of Agriculture publication.

The deterioration is of a twofold kind. The plant, starved of lime, is less capable of making use of the other foods which the soil contains. The clay soils, or many of them, bereft of lime become stickier, harder to work, and less easy to aerate. Most clays require lime, but some of them, just like the silty soils of the millstone grit of Yorkshire, refuse to change their state when they are limed. Others, however, become more friable, lose their stickiness, and improve both physically and vitally.

So far as is known at present, the only economical means of betterment of those clay soils which are refractory to lime are by the use of farmyard manure and humus or other organic materials. Therefore, where sufficient supplies of farmyard manure were not available, much of these difficult clay lands has been laid down or tumbled down to grass. Experiments at Jealott's Hill show that not a little can be done in the laboratory to improve the physical state of samples of clay refractory to the ameliorating influence of lime. Aluminium sulphate helps, and so in a lesser degree does sulphate of iron, but it cannot yet be claimed that either of them is of any use when employed on a large scale on the farm. The experiments will go on because if they brought results of practical value they would reduce the labour of cultivating the lime-refractory clay soils; convert four horse-land to land that could be ploughed with two horses, and make it dryer, warmer, and earlier.

Lime, like other plant foods, disappears rapidly from a soil. Lump lime put on a field persists steadily in finding a lower place, until presently the chunks deposited on the surface may be found buried three feet deep in the soil. Rain dissolves lime and carries it away in the

drainage. The plant needs but little, but that little it must have.

It is universally recognized that the greater part of Great Britain is deficient in lime. Large areas are naturally deficient. Even in limestone districts soils may be found, the upper layers of which have lost all the stores of lime with which they were originally provided. Caps of clay on the chalk downs of southern England show by the ling and other lime-shy plants which grow on them that although the soil stands on a foundation of chalk, there is no lime left in it.

From early times right down to the first decade or so of this century the liming of the land was a ritual faithfully observed by farmers. They used to give heavy periodic dressings in one form or other. With hard times and increasing cost of material and labour, liming had to go.

To compensate completely for the existing deficiencies of lime in the soil requires heavy and costly dressings. There is, however, an increasing mass of evidence to show that applications of lime much lighter than those required to remedy completely lime deficiency are of immediate and large benefit. Therefore the farmer who knows that his land lacks lime should not be deterred by reason of the high cost which heavy dressings entail from giving any at all, but should apply as frequently as he can light dressings of finely ground lime or chalk. It is certain that so small an amount as 7 cwt. or even less to the acre would be found to pay in the returns which the farmer would get from his crops.

Instead of spreading lime broadcast and thereby in any case offering the greater part of it as a free gift to Nature, the small dressing should be so distributed as to be near

the roots of the crop. If the form used is caustic, it must be spread well before a crop is sown, but if applied in the mild form of ground limestone or chalk it can be drilled with the seed or at any other convenient time.

The home supplies of lime are far in excess of the farmers' requirements, but the centres of production are not distributed uniformly over the country, a fact which presses hard on the farmer in districts remote from sources of supply.

There is scope for a large national scheme of liming agricultural land, and it is certain that were the effort made the country as a whole would be amply repaid in the larger production and better food to which it would lead.

THE SCIENTIFIC USE OF FERTILIZERS

The straightforward and economic uses of fertilizers on the farm are described in Chapter IX, but scientific knowledge of fertilizers can be used to help the farmer more than that. Soils vary; the climate of this country is not uniform. Different crops have different food requirements; one and the same crop needs more food at one time than at another. Some varieties of a crop respond more generously to fertilizers than do others. Some crops are greedy, some are frugal. Some soils are hungry, some are fat. All these peculiarities have to be inquired into by experiment, and so soon as experiment has resulted in a conclusion of practical use to the farmer it must be tried out on the farm and, when established, brought quickly and generally into practice.

Greedy crops. Take, for example, a greedy farm crop, one of the cabbage tribe such as kale. Kale, like grass, has an almost unappeasable appetite for nitrogen and growers,

particularly market-garden growers, are well aware of the fact. Yet on the farm this crop rarely receives the amount of nitrogen of which it can make use.

The results of experiment with marrow stem kale, in 1929–31, at Jealott's Hill are illustrated in Chart VIII. In 1929 the yields were:

No nitrogen	$9\frac{1}{2}$	tons to the acre.
2 cwt. nitrogen fertilizer . .	$15\frac{1}{3}$	,, ,,
4 ,, ,, nearly	19	,, ,,
6 ,, ,, . .	22	,, ,,

That is, the application of 6 cwt. of nitrogen fertilizer to the acre results in a crop 130 per cent. larger than that which received no nitrogen.

The yields in the following year show similar increases but at a lower level. In the year 1931, however, when the experiment was used to find out, first, how large a dressing could be recommended with confidence and, second, where the limit of the increase due to nitrogen would be reached, the yields were:

No nitrogen . . .	13	tons to the acre.
3 cwt. nitrogen fertilizer .	$17\frac{1}{2}$	,, ,,
6 ,, .	$22\frac{1}{2}$	,, ,,
9 ,, ,, .	25	,, ,,

As the chart shows, the limit was not reached even at 9 cwt. To be on the safe side, however, it may be recommended that the kale crop should receive under average farm conditions a dressing of nitrogen at the rate of 4–6 cwt. per acre. A larger amount will give a bigger crop but the increase may be bought at too high a price.

Balanced rations of food for plants. The potato is another example of a greedy farm crop. Its greediness,

however, is conditional. When supplied with a moderate dressing of the three plant foods, as, for example, that

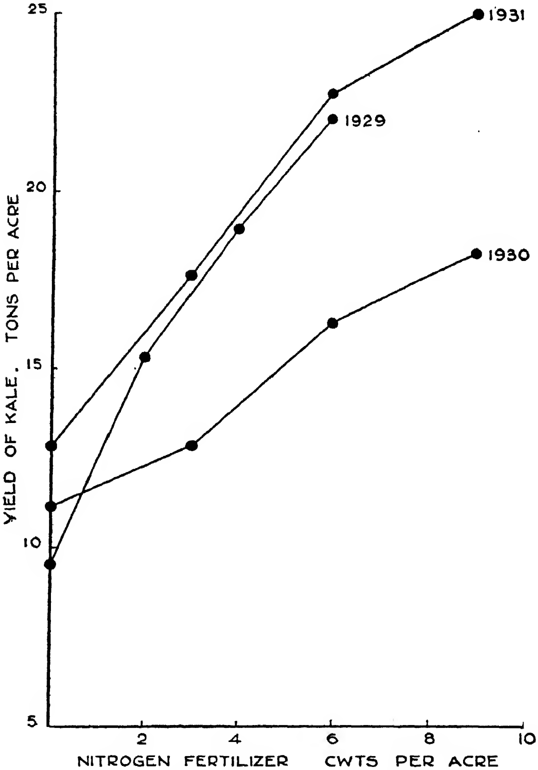

CHART VIII. Increases in Yield of Marrow Stem Kale with Increasing Supplies of Nitrogen.

recommended on page 142, it responds by a good increase of yield. Increase the nitrogen: there is no further response; but increase the potash as well as the nitrogen and

a higher yield results. A further addition of nitrogen also remains ineffectual unless the potash is increased proportionately. The potato requires two crutches of equal length to push it up the stairway of growth.

These results apply to Great Britain. In Northern Ireland it seems that phosphates, unless supplied more liberally than is necessary in England, limit the yield.

The curious relation between nitrogen and potash just described was discovered at Rothamsted and has been confirmed at Jealott's Hill, where a similar relation has been shown to exist in the case of the sugar-beet crop.

Nitrogen-thrifty crops. The cereals, wheat, barley, oats, unlike the leafy crops, can make no lavish use of nitrogen (see p. 31). Excess of nitrogen does them harm. It provokes undue development of leaf and haulm and reduces instead of increases the harvested grain.

The relatively frugal use of nitrogen by the wheat plant has far-reaching effects on agricultural yields in Great Britain. Under British conditions of climate, wheat and oats when grown on soil too rich in nitrogen are apt to lodge badly. It is as though the plant grows old too soon, and losing the resiliency of youth its haulm can no longer withstand the buffeting of winds or the beating of rain. The corn lodges, giving the farmer much trouble with its harvesting and often losing on the ground not a little of the grain which should have remained in the ear.

Apprehension of this misfortune makes the farmer sparing in the use of nitrogen on his wheat crop. Yet, as the Rothamsted and Jealott's Hill figures show and as is proved also by the results obtained on the Recorded Farms (p. 27), unless wheat receives in the spring a dressing of nitrogen its yield is low (17·7 cwt. to the acre),

and that even on land which contains plenty of nitrogen in the form of humus.

The average yield of wheat in Great Britain is too low, and the lowness is due in no small measure to the fact that wheat does not receive the moderate amount of nitrogen which it must have if it is to tiller well. Failing to produce enough tillers the wheat has few instead of many fertile ears and the yield is therefore poorer than it should be. The same is true of the other cereals—oats and barley.

The case of autumn-sown wheat provides a specially striking example of the dilemma in which the farmer finds himself. The wheat is sown after the temporary ley has been ploughed up. The organic substances assembled by the roots of grasses and clovers, undergoing decay, give rise to humus, the nitrogen of which is supposed to be wholly or mainly at the disposal of the wheat crop.

Where, as in the northern parts of the country, it is customary to give a dressing of farmyard manure before ploughing up the seeds ley there is a yet further amount of organic nitrogen available, or apparently available, to the ensuing corn crop. Confident that the land is richly supplied with nitrogen and is in all respects in good heart, the farmer only too frequently gives neither nitrogen nor mineral food to the autumn-sown wheat. Yet there are some soils which must receive phosphates and potash if the wheat is to do well. They should get the fertilizers after the land has been ploughed up and is ready for sowing with corn. There are other soils which, in spite of their richness in humus nitrogen, yield better crops when they get a dressing of nitrogen fertilizer. The nitrogen, however, should be applied in the spring, and indeed where all three foods are required they may be applied together at

this time in the form of a complete fertilizer. When spring follows a wet winter and the farmer has to survey the ravages which have been wrought on his crop, he knows that the first step to take in order to improve its condition is to dress the wheat with nitrogen. When, however, the wheat looks fairly well and the leaves are not too yellow, he withholds the nitrogen for fear of the lodging which it may induce.

The results of experiment dispute the wisdom of this course. It is true that risk of lodging must be run. A dressing of 2 cwt. to the acre of a quick-acting nitrogen fertilizer must be given. The risk of lodging will not be greatly increased and in no other way can a good crop be got.

The general practice is to apply the whole of the nitrogen early; but experiments at Jealott's Hill show that this custom should be reconsidered.

The wheat is sickly and it may be in broken ranks! First aid must be given at once. A light dressing, half of the total amount to be applied to the crop, is given so soon as the weather is propitious. Or the wheat plant is looking well and the rows are full. Yet in spite of fair appearances nitrogen is necessary if the crop is to give an abundant yield.

The question is when to give it? The general practice among farmers, if they use nitrogen at all, is to apply it fairly early. The experiments indicate that the time of application is all-important. If the nitrogen is given too soon the crop does not make full use of it. If it is given too late though it brings about an increase in straw it reduces the yield of grain. Not until the crop has begun to grow with vigour should the good stand of wheat receive any nitrogen. When, and not until, it has begun to grow well,

a dressing of 2 cwt. nitrogen fertilizer is applied. In the case of a sickly crop which has already received a half dressing, the remainder should be given immediately after vigorous growth has begun.

In Berkshire, on the fairly heavy farm land at Jealott's Hill, it has been found in the course of three years' experiments that the middle of May is the right time, and that when the nitrogen is applied then, the grain benefits at the expense of the straw: the opposite of what happens with an earlier dressing.

Numerous experiments will have to be made in other parts of the country and on different types of soil in order to determine the right moment of application in each individual case. It will undoubtedly be found that although no precise date can be fixed for all conditions, yet the wheat plant itself will show at what phase of its development the spring application should be made.

Farmers with sore memories of wet harvests and lodged corn will be bound to ask whether nitrogen on wheat ever pays for its lodging. The answer is—if yields are to be increased, nitrogen must be given. If the dressing is to do more good than harm, it must be given at the right time. Without the application, yields, where they are small, will remain small.

The reason why this must be so is because humus nitrogen, plentiful though it may be, is hoarded by the soil and not paid out readily enough in the early months of the year. The spring is the time when the foundations of crop production are laid by the wheat plant. The young plant has to produce enough and yet not too many vigorous branches which, appearing above ground as tillers, produce the fertile ears. Once the time is past for the vigorous

production of tillers, the belated addition of nitrogen has no effect upon it. The nitrogen may make them grow sturdier but it cannot now make them fertile.

Though a disastrously wet summer may rob farmers who follow these recommendations of some of the fruits of their enterprise, yet on the average and over a period of years they will be the gainers, and the yield of wheat in Great Britain will be raised to a level more comparable with that of Holland.

Crop predilections. All crops require sufficient supplies of the three essential fertilizers, but some crops show a special partiality for one or more of them. Kale has a predilection for nitrogen. Maize is avid for phosphates. Swedes and turnips also make large demands on phosphates. Mangolds and sugar beet require a plenteous supply of potash. The food which gets stored in their roots is made in the leaves. Potash helps them to make it. The food has to pass in the form of sugar from the leaf to the root. Potash accelerates the passage. Where there is not enough of it in the soil, the roots remain small and their feeding value is low.

Potash also plays an important although obscure part in maintaining the health of plants. As has been stated already, it is particularly beneficial in sunless seasons. Potash confers hardiness on winter crops, aids fruit trees to resist disease, and helps to confer on the fruit a brighter colour.

The lighter lands of this country are apt to be deficient in potash and much loss follows from a failure to recognize the defect. Much of the heavy land is well supplied with potash and farmers on such lands need only experiment very cautiously in its use. In their experiments they will remember that as yields rise, larger quantities of each of

the food materials are required by the crops so that an amount sufficient for a low level of production will not be enough for a higher level.

Farmyard manure. The reasons why fertilizers must be used universally and continuously if crops are to give full yields have already been stated. The demands of the crops must be met and the wastage from the soil made good. Unless, therefore, the ever-increasing shortage of plant food is repaired, the soil decreases in fertility and the production on the farm grows less. To maintain the fertility of a soil, the farmer must not only make sure that the plant foods are there, he must also see to it that the state of the soil is congenial to the growth of crops. A heavy soil left to itself gets water-logged and the roots of plants are suffocated. A light soil dries out so rapidly in times of drought that crops, unable to obtain enough water, stop growing, wilt, and wither. At times of spring drought all vegetation may stand still and only on deep, well-cultivated soils may the check prove to be transitory.

It is in its power of ameliorating the state of the soil that farmyard manure holds the advantage over artificial fertilizers. It does not supply plant foods in a perfect proportion, but it does help to improve soils. Farmyard manure makes a heavy soil lighter and better aerated and enables a light soil to hold more water and to resist drought better. The roots of plants growing in soil well supplied with it are able to develop strongly and to absorb the water and plant foods which the crop must have. Artificial fertilizers also assist in this direction, but to a lesser extent. They make the plant more efficient by causing it to become less extravagant in its water consumption; but by themselves they cannot directly render the same service

in improving the state of the soil as is given by farmyard manure. Therefore farmyard manure and artificial fertilizers must both be used, the one to supplement the other.

Analysis shows that whereas farmyard manure is relatively rich in nitrogen, it is relatively poor in mineral plant foods, particularly phosphates. The farmer who puts on a dressing of from 10 to 15 tons per acre may think that he has given all the plant food that the crop can require. He has not. It may or may not provide enough nitrogen. That depends on the kind of crop. It does not supply enough phosphates or potash. To use farmyard manure alone is to use it uneconomically. The proper course is to supplement it with phosphates, and where the soil contains no natural reserves potash also must be added.

The soil bank. The behaviour of the nitrogen of farmyard manure requires further consideration. The condition in which it occurs is a curious one. Much is in the form of complex compounds which, because they contain carbon, are called organic compounds. Farmyard manure, also, like the soil itself, teems with microscopic organisms, bacteria, and the like which use organic carbon and nitrogen compounds as food. A continuous competition for nitrogen and other food materials is waged between the roots of plants and the bacteria and other micro-organisms of the soil. The addition of farmyard manure to the soil intensifies the conflict. The micro-organisms which it contains, increasing and multiplying, bring reinforcements to the microscopic battalions already in the soil. The augmented numbers take up and store more of the nitrogen contained in the farmyard manure. The roots of crops may suffer a temporary reverse. For the moment they get

less nitrogen than they need. There will be plenty more for them later on when the bacteria die and release their stored-up share, but that is at best only a partial compensation to the crop. It needs nitrogen now, but it is not there. Growth is checked. The crop suffers. A timely application of nitrogen prevents the trouble. There is now enough nitrogen for all; both crop plants and bacteria. The crop flourishes. Yields increase, and the stored-up food in the bodies of the bacteria add presently to the fertility of the soil.

The results of experiment illustrate these facts. Equal areas of land, in which potatoes were to be planted, were supplied with farmyard manure in progressively larger amounts: one got 10 tons to the acre, a second 20 tons, and a third 30 tons; the fourth received none, but in its stead a liberal dressing of a complete fertilizer containing nitrogen, phosphates, and potash. The natural potash of the soil, along with that in the 20- and 30-ton dressings of farmyard manure, was adequate for a good crop, but the 10-ton dressing did not supply enough and was therefore supplemented by additional potash. To ensure that there should be no deficiency of phosphates, liberal dressings of a phosphatic fertilizer were given to each of the three areas supplied with farmyard manure. Each of the four areas therefore contained quantities of phosphates and potash ample for the production of a large crop.

The yields were:

Dressing	*Tons of potatoes*
1. 10 tons farmyard manure, per acre	9·59
2. 20 ,, ,, ,,	10·88
3. 30 ,, ,, ,,	11·90
4. Complete fertilizer (4 cwt. sulphate of ammonia, 5¾ cwt. superphosphate, 4 cwt. muriate of potash)	12·17

It may be taken as an agricultural axiom that two crops of the same plant, of equal size, consume about equal quantities of nitrogen. It therefore follows that since neither the 10-ton nor the 20-ton farmyard manure areas yielded so much as the area dressed with artificial fertilizer only, the potatoes growing in them did not get all the nitrogen they required for large crop production. Yet even 10 tons of farmyard manure contain far more nitrogen than was given to the area dressed with the complete fertilizer. But although it contains plenty of nitrogen, farmyard manure only pays it out slowly. The run of the crop yields in the areas supplied with 10, 20, or 30 tons of farmyard manure indicates further that the amount of nitrogen paid out in a form ready for use is proportional to the total supply of nitrogen in the soil bank. When the bank reserves are very high, as is the case in the area which received 30 tons, the paying out of nitrogen from the farmyard manure is on such a liberal scale that the plant gets all it can use and therefore produces a crop of much the same size as that given by the complete fertilizer. The soils supplied with 10 and 20 tons of farmyard manure, although they got in this way much more nitrogen than did the soil to which the artificial fertilizer was applied, pay it out so grudgingly that the plant does not get as much as it needs and in consequence the yields suffer.

These conclusions must not be taken to mean that farmyard manure is to be measured solely by the amount of nitrogen with which it provides growing crops. It has already been mentioned that farmyard manure improves the physical condition of the soil, and it is no less certain that in ways more obscure, but equally potent, farmyard manure is of the greatest value to the farmer.

A possible explanation of the obscurer ways in which farmyard manure benefits the land lies in its relation to the soil bacteria. The manure itself contains vast numbers, so does the soil; but soil bacteria are of many kinds and not all of them work towards the improvement of soil fertility. Farmyard manure is rich in compounds which contain carbon, and it is probable that the value of these compounds lies more in their carbon content than in their nitrogen. The carbon compounds supply food for bacteria. The bacteria convert the carbon, together with nitrogen and phosphates, into parts of their bodies. In course of time the bacteria decay and, small though they are, their number is so great that in the decay significant quantities of materials of high feeding value are liberated and become available to the roots of the crop plant.

While the compounds are in bacterial storage they are of no use to the plant; but when decay of the dead bacteria sets in, the food substances which they contain begin to be released and go on being paid out gradually, and so the crop gets them.

The view that farmyard manure owes part of its value to the carbon which it contains receives some support from the methods used by good market-gardeners and fruit growers to increase soil fertility. They are at pains to supply to the soil such substances as wool waste, shoddy, leather waste, dried blood, and other organic animal remains, as well as nitrogen, phosphatic, and potash fertilizers. These organic substances are rich in carbon. They are as a rule not of a kind which contribute very much to the improvement of the physical state of the soil, and it may prove that it is the carbon of their organic compounds which bestows on these organic fertilizers a large part of

such virtues as they possess. Experiments now being carried out by Mr. L. J. D. Mackie have for their object to discover whether the value of organic fertilizers of the kinds just mentioned is due to the carbon they contain, to their physical effects on the soil, or to both. The results will help to determine whether their use should be continued and extended, or whether it may not prove possible by judicious timing of application of fertilizers to get equally good results without the use of these organic materials which, as chemical analysis shows, contain smaller proportions of the essential plant foods than do the ordinary complete fertilizers.

What is true of the nitrogen contained in farmyard manure is true also, albeit to an extent which has not yet been measured, of the nitrogen contained in fertilizers.

No more than the nitrogen of farmyard manure does the nitrogen of a fertilizer lie inert and passive in a soil. Some of it also has to be paid into the soil bank.

The sharing out of a nitrogen fertilizer between bacteria and the roots of a crop is illustrated by the following observations made by Messrs. G. E. Blackman and A. H. Lewis.

A dressing of sulphate of ammonia or nitrate of soda is given to a parcel of grass land. Some of the fertilizer passes immediately into the grasses; some remains in the soil. If at a given moment an attempt is made to recover the moiety which remains in the soil, only part of the nitrogen can be got back, but if another attempt is made a week later the amount reclaimable is not less, as might be expected, but may be double that which was got at the first attempt. In the interval between the application of nitrogen and the first attempt at recovery some of the nitrogen was immobilized. Locked in the bodies of soil bacteria it

could not be recovered. Presently, however, the brief lives of numerous successive generations of the bacteria came to an end—a week probably covers many thousands of generations of things so minute and so active as these.

In the interval also temperature and other changes have taken place in the soil. In one set of conditions the constructive bacteria dominate and carry on the work of converting simple forms of nitrogen into organic substances which they store in their bodies. In another set of conditions the bacteria which are destroyers come into action. They undo step by step the constructive work of their rivals: break down complex organic compounds by many stages into the simpler forms out of which those compounds were constructed. So inimical are some bacteria to soil fertility that they may exercise the final disruptive action of liberating nitrogen altogether from its association with other elements: setting it free in gaseous form to augment the already extravagant supplies contained in the atmosphere.

In yet other conditions specialists among the bacteria, operating upon any ammonia which may be in the soil, change it into nitrates, which in turn may be seized on by the plant or by bacteria and changed again and locked up in organic form.

What the conditions are which control this conversion of nitrates into organic compounds is not known. But it is certain that when the bacteria which do the work find their opportunity, they act with extraordinary swiftness and efficiency. The supposition that a nitrate form of fertilizer lies all of it unchanged in the soil is erroneous. Bacteria need it; plants need it. Both get it, and whilst the bacteria hold their share the plants may not have it.

For this reason the fluctuations in the amount of nitrogen recoverable when a nitrate fertilizer is applied to the soil are often more violent and more extreme than those of a fertilizer which has its nitrogen in the form of ammonia. This at all events is the case in pasture, and it helps to prove what other facts also tend to show—that the plants of grass land are better able to compete with bacteria for possession of ammonia than they are for nitrate nitrogen.

There is no doubt that the immobilization discovered in the experiment is the result of vital activity in the soil. Anaesthetics affect micro-organisms and mankind alike. Put the soil under an anaesthetic and the vital activities of its bacteria are suspended. When this is done and attempts are made to recover the nitrogen added to the soil in the form of nitrate or ammonia there is found to be no variation in the amount reclaimable at different times. The experiment draws a new picture of the relation between soil and nitrogen. It shows that the soil keeps on behalf of plants nitrogen in two accounts. The one can be drawn upon at any time—the current account; notice is required for the withdrawal from the other—the deposit account. The soil bank is a living bank, and as yet but little is known of the rules which govern its operation. Discovery of the rules will lead to the elucidation of the mystery with which soil fertility and soil infertility is now enshrouded. Progress is being made, but it must be long before any one is able to say with scientific exactitude why one soil is fertile and another sterile.

Response of varieties to nitrogen. Another line of advance which is being actively explored is that indicated by the fact that varieties of one and the same crop plant differ in the degree of their response not only to soil and climatic

conditions but also to fertilizers. The farmer naturally wants to grow varieties most suited to his land, but the varieties from which he has to choose are numerous. He cannot try experiments with them all, and it may therefore and does happen that he is not growing the best for the conditions under which he farms. The National Institute of Agricultural Botany, which has done so much to improve varieties of farm crops, has shown that increased production, amounting it may be to so much as 10 per cent., would take place automatically were each district to grow only the varieties most suited to it. Professor Stapledon has shown that a similar conclusion holds good for the plants of grass land, and there is no reason to suppose that it is not true for all other crops.

A similar relation holds between varieties and response to fertilizers. Four varieties of wheat—Squarehead Master, Steel, Chevalier, and Iron III—were grown in 1931 at Jealott's Hill, each in two series of plots. One series received a relatively small amount of nitrogen, the other a larger amount. They all contained a sufficiency of phosphates and potash. The larger nitrogen dressing gave consistently larger yields, but the amount of increase differed according to the variety.

The results were:

		Cwts. Grain	*Cwts.* Straw
Squarehead Master:	increase due to extra nitrogen	2⅔	6⅔
Steel, and Iron III	,, ,, ,,	3¾	10½
Chevalier	,, ,, ,,	7½	17

The relatively small differences between Squarehead Master, Steel, and Iron III may have no significance, but the largely increased yields given by Chevalier prove

that this variety responds with exceptional generosity to liberal supplies of nitrogen.

It is of course too soon to put the results of an isolated experiment into general practice, but the result, the last to be recorded here, shows that there still remain large and fertile fields for exploration of the ways in which the scientific use of fertilizers may be made to increase yet further the production of food grown in these islands.

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APPENDIX I (*see Chapter II*)

Table A

Annual Consumption of Food in Great Britain and Northern Ireland

	Total	*Home*	*Imported*
Corn (million tons)	13·27	4·38	8·89
Vegetables, fruit and vegetable products (for human food) (million tons)	11·21	8·78	2·43
Sugar* (million tons)	1·74	0·42	1·32
Meat, including eggs (million tons)	3 31	1·36	1·95
Offals (million tons)	1·70	0·25	1·45
Cakes and other meals, including brewers' grains, &c. (million tons)	2·19	0·49	1·70
†Dairy produce in terms of liquid milk (million gallons)	3,459	1,330	2,129

* Estimated on 1930 acreage.
† Does not include milk fed to calves.

Table B

Food used for Human Consumption, feeding of Farm Animals, Commercial Purposes, Distilling, &c.

	Human Consumption	*Animal Consumption*	*Commercial*
Corn (million tons)	6·46	5·22	1·59
Vegetables, fruit and vegetable produce (million tons)	11·21	..	..
Sugar (million tons)	1·74	..	..
Meat, including eggs (million tons)	3·31	..	..
Offals (million tons)	..	1·70	..
Cakes and Meals (million tons)	..	2·19	..
Dairy produce in terms of liquid milk (million gallons)	3,459	..	..

Table C

Area of Agricultural Land in Great Britain and Northern Ireland

(In thousand acres)

	England and Wales	*Scotland*	*N. Ireland*	*United Kingdom*
Arable excluding temporary grass	7,864	1,667	570	10,101
Temporary grass*	2,473	1,501	664	4,638
	10,337	3,168	1,234	14,739
Permanent grass*	15,266	1,511	1,219	17,996
	25,603	4,679	2,453	32,735
Rough grazings*	5,131	9,672	535	15,338
	30,734	14,351	2,988	48,073

* Average for 1924–30, except for Northern Ireland, which is the average for 1924–9.

Table D

Area under the Principal Agricultural Crops: Average for the years 1924–30

(In thousand acres)

	England and Wales	*Scotland*	*N. Ireland*	*United Kingdom*
Wheat	1,478	54	5	1,537
Barley	1,165	123	2	1,290
Oats	1,845	907	316	3,068
Beans and peas	325	3	1	329
Potatoes	484	141	151	776
Turnips, swedes, and mangolds	1,071	385	46	1,502
Sugar beet (1930)	347	2	..	349
Orchard fruit	244	1	9	330
Small fruit	68	8		

Table E

Number of Live Stock, England and Wales, Scotland, and Northern Ireland, 1924–30

	England and Wales	Scotland	N. Ireland	United Kingdom
Cattle	6,059,970	1,208,608	696,754	7,965,332
Sheep	16,224,265	7,361,051	586,581	24,171,197
Pigs	2,630,291	168,012	183,472	2,981,775

Table F

Agricultural Holdings

	England and Wales	Scotland	N. Ireland	United Kingdom
Over 1 acre, not exceeding 50 acres . .	254,929	50,308	87,239	392,476
Over 50 acres, not exceeding 100 acres .	61,703	10,207	11,310	83,220
Over 100 acres, not exceeding 150 acres .	31,998	5,947		
Over 150 acres, not exceeding 300 acres .	34,957	6,818	3,748	98,102
Over 300 acres . .	12,236	2,398		
Total	395,823	75,678	102,297	573,798

Table G

Number of People employed in Agriculture, 1929

GREAT BRITAIN

	Regular workers	*Casual workers*	*Total*
England and Wales . . .	643,977	126,275	770,252
Scotland	101,083	16,951	118,034
Great Britain	745,060	143,226	888,286

NORTHERN IRELAND

Members of family	150,551
Permanent labourers	27,740
Casual labourers	13,076
	191,367

The occupier, his wife, and domestic servants are not included in the figures for Great Britain, but the total number of persons who gain a direct livelihood from agriculture may be estimated at:

Great Britain .	1,209,177
Northern Ireland	191,367
	1,400,544

APPENDIX II (*see Chapter II*)

Table A

Areas under Crops and Grass, and Numbers of Live Stock

GREAT BRITAIN ONLY

1930 and 1868

	1930		*1868*	
	Area	*Per cent.*	*Area*	*Per cent.*
Total area under crops and grass	30,021,165		29,955,694	
Arable land	12,904,764	43·0	17,819,658	59·5
Permanent grass	17,116,401	57·0	12,136,036	40·5
Temporary grass	3,922,734	30·4	3,960,008	22·2
Wheat	1,400,077	10·9	3,652,125	20·5
Barley	1,126,796	8·7	2,151,324	12·1
Oats	2,640,309	20·5	2,757,053	15·5
Potatoes	548,018	4·2	541,543	3·0
Green crops (roots, &c.)	1,446,368	11·2	2,542,531	14·2
Bare fallow	299,610	2·3	958,221	5·4
Other crops	1,520,852	11·8	1,256,853	7·1
Cattle	7,085,775		5,423,981	
Sheep	23,965,394		30,711,396	
Equivalent per 100 acres of crops and grass	39·5		38·6	

Cattle equivalent—5 sheep = 1 beast.

Table B

GREAT BRITAIN, BY AGRICULTURAL DIVISIONS

Changes in area of Arable and Grass land with accompanying changes in numbers of live stock in each of the agricultural divisions in Great Britain.

Division*	*Millions of acres*						*Millions*				*Cattle equivalents per 100 acres crops and grass*	
	Under crops and grass		*Arable land*		*Permanent pasture*		*Number of cattle*		*Number of sheep*			
	1930	*1868*	*1930*	*1868*	*1930*	*1868*	*1930*	*1868*	*1930*	*1868*	*1930*	*1868*
Eastern . .	2·74	2·89	1·75	2·21	0·99	0·67	0·34	0·26	0·57	2·07	16·5	23·3
N. Eastern . .	3·16	3·08	2·12	2·30	1·04	0·77	0·46	0·41	1·25	3·11	22·4	33·7
S. Eastern . .	2·35	2·66	0·93	1·75	1·43	0·90	0·42	0·29	1·26	2·87	28·6	32·4
E. Midland . .	2·75	2·73	0·83	1·48	1·92	1·28	0·64	0·47	1·27	2·73	32·5	37·2
W. Midland . .	2·74	2·78	0·79	1·46	1·95	1·32	0·67	0·42	1·48	2·47	35·2	32·8
S. Western . .	2·97	2·70	1·05	1·52	1·92	1·18	0·87	0·60	1·71	2·70	40·6	42·2
Northern . .	2·93	2·98	0·91	1·40	2·02	1·58	0·69	0·52	2·84	2·74	42·9	35·9
N. Western . .	2·98	3·00	0·80	1·12	2·17	1·88	0·97	0·77	1·83	2·03	44·8	39·2
England (Total) .	22·62	22·82	9·18	13·24	13·44	9·58	5·06	3·74	12·21	20·72	33·1	34·5
Wales (including Monmouth .	2·76	2·72	0·66	1·17	2·10	1·55	0·78	0·63	4·10	2·87	58·0	42·8
Scotland . .	4·64	4·41	3·07	3·40	1·57	1·02	1·24	1·05	7·65	7·11	59·7	56·0

* Agricultural Divisions of England: *Eastern.* Bedford, Hunts., Cambs., Isle of Ely, Suffolk, Essex, Herts., Middlesex. *N. Eastern.* Norfolk, Lincs., Yorks. (E.R.). *S. Eastern.* Kent, Surrey, Sussex, Berks., Hants, Isle of Wight. *E. Midland.* Notts., Leicester, Rutland, Northants, Bucks., Oxon., Warwick. *W. Midland.* Salop, Worcester, Gloucester, Wilts., Hereford. *S. Western.* Somerset, Dorset, Devon, Cornwall. *Northern.* Northumberland, Durham, Yorks. (N.R.), Yorks. (W.R.). *N. Western.* Cumberland, Westmorland, Lancaster, Chester, Derby, Staffs.

APPENDIX III (*see Chapter III*)

Nitrogenous Fertilizers used in the British Isles

1926/7 . . .	40,500 metric tons nitrogen.
1927/8 . . .	42,000 ,, ,,
1928/9 . . .	49,500 ,, ,,
1929/30 . . .	48,500 ,, ,,

APPENDIX IV

TABLE A

Agricultural Consumption of Nitrogen in Holland, Great Britain, and the Holland Division of Lincolnshire

	Consumption of Nitrogen (lb. N. per acre)		
	Holland	*Great Britain*	*Holland Division of Lincolnshire*
In fertilizers . . .	31·6	3·1	14·0
In farmyard manure* . .	15·2	14·7	14·7
	46·8	17·8	28·7
In soil 'humus'*	3·2	21·0	17·4
TOTAL	50·0	38·8	46·1

* The figures for the consumption of inorganic and organic manures vary much more widely than the corresponding crop yields. This discrepancy is largely due to a difference in the type of farming, since in Great Britain temporary leys figure prominently in the rotation, whilst in Holland they are of minor importance. These leys contribute an appreciable amount of nitrogen which must be taken into account. This has been done as is shown in the figure for 'humus' in the table. It has been assumed that 50 per cent. of the nitrogen in farmyard manure and in the ploughed-down sod of the leys is available to the crop. The wide separation of the pastoral from the arable area in Holland leads to a larger use of farmyard manure on the grass land and a smaller use on the arable. This fact would seem to bring the total Dutch consumption of nitrogen on arable land much closer to that of Great Britain, but on the other hand there is but little doubt that the allowance of 50 per cent. of the total nitrogen in the ploughed-up leys, as available to succeeding crops, is too high. In all probability the allowance should be nearer to 25 than to 50 per cent. and, if so, the figures of the table would remain a fair indication of the relative consumption of nitrogen in the two countries.

Table B

Yields of Wheat, Barley, Oats, and Potatoes in Holland, Great Britain, and the Holland Division of Lincolnshire

	Average yield (cwt. per acre)			
	Wheat	*Barley*	*Oats*	*Potatoes*
Holland	22·8	23·3	15·4	136*
Great Britain	17·8	15·5	15·0	120
Holland Division of Lincs.	23·1	19·9	22·9	144

* Estimated from yields of potatoes grown for various purposes.

APPENDIX V (*see Chapter IV*, p. 41)

Chemical Composition of Grass grown under Intensive Management

	Range of values		*Average value*
	Lowest	*Highest*	
	Per cent.	*Per cent.*	*Per cent.*
Ether extract	2·9	8·8	6·2
Fibre	14·0	24·3	20·2
Crude protein	13·7	31·1	22·7
Nitrogen-free extractives	29·5	50·8	40·5
Ash	8·5	14·0	10·4
Lime (CaO)	0·51	1·19	0·82
Phosphoric acid (P_2O_5)	0·40	1·06	0·75

APPENDIX VI (*see Chapter IV*, p. 42)

*Productivity of grass land, compared with that of an arable crop (oats)**

	Yields per Acre			
	Crude protein	*Digestible true protein*	*Starch equivalent*	*Net energy*
	lb.	*lb.*	*lb.*	*Therms*
1. Oat grain . . .	305·7	213·6	1771·9	1897·7
,, chaff . . .	19·6	5·5	112·1	120·0
,, straw . . .	200·0	52·6	894·9	958·4
Total	525·3	271·7	2778·9	2976·1
2. Grass with nitrogen .	1214·9	812·0	3860·0	4134·1
,, For hay without nitrogen . . .	458·0	228·0	1993·0	2133·0

* Note: The oat crop is taken at:

Grain . . .	26½ cwt
Straw . . .	47 ,,
Chaff . . .	3½ ,,
Total	77 cwt.

This crop was grown at Jealott's Hill. The yield of pasture grass shown in the table by no means represents the maximum possible, and has in point of fact often been surpassed.

APPENDIX VII (*see Chapter V*)

JEALOTT'S HILL SMALL HOLDING (46 acres of grass land)

PROFIT AND LOSS ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1931

	£	s.	d.	£	s.	d.
To *Purchases, &c.*						
Cattle				627	16	0
Pigs				30	0	0
Poultry				7	10	0
Horses				30	0	0
Foodstuffs:						
Concentrates	241	3	8			
Roots and Oat Hay	36	7	6			
				277	11	2
Fertilizers				62	11	9
Rent				120	0	0
Wages (Holder and Casual)				186	19	3
Hired Horse and Tractor Labour				10	18	4
Overhead Charges				50	12	8
Sundries (Milk Carriage, Recording, Dairy Materials, &c.)				92	19	7
				1,496	18	9
,, *Valuation* at Commencement.						
Cattle	450	0	0			
Pigs	13	0	0			
Poultry	72	0	0			
Hay	164	0	0			
Manurial Residues and Farmyard Manure	24	5	0			
Implements	127	6	9			
				850	11	9
				2,347	10	6
,, *Profit* for the year				125	9	2
				£2,472	19	8

Acres per cow equivalent for 12 months = 1·9.

	£	s.	d.	£	s.	d.
By *Sales, &c.*						
Cattle				490	9	3
Horses				30	0	0
Pigs				95	5	5
Poultry and Eggs				79	4	5
Hay				75	6	0
Farmyard Manure				12	10	0
Milk				713	14	4
				1,496	9	5
,, *Valuation* at End.						
Cattle	575	0	0			
Poultry	36	0	0			
Hay	182	0	0			
Foodstuffs, &c.	10	18	10			
Implements	115	1	8			
Manurial Residues and Farmyard Manure	57	9	9			
				976	10	3
				£2,472	19	8

Total milk produced.	*Gallons.*
Sold	12,519
Allowed to Holder	182
Calves	503
	13,204

APPENDIX VIII (*see Chapter VI*)

Present Production of Crops and Estimated Increase obtained by the use of Fertilizers

GREAT BRITAIN AND NORTHERN IRELAND

Crop	*Acreage Average 1924/30*	*Average yield 10 years 1920/9 per acre*	*Total net crop (less seed)*	*Increase due to 1cwt.S/A per acre*	*Total net crop at increased yield (less seed)*
		Cwt.	Tons	Cwt.	Tons
Wheat . . .	1,537,000	17·8	1,260,000	2·5	1,452,000
Barley . . .	1,290,000	15·8	929,000	3·2	1,135,000
Oats . . .	3,068,000	14·6	2,025,000	2·6	2,424,000
		Tons		Tons	
Potatoes . .	776,000	6·3	4,229,000	1·0	5,005,000
		Cwt. Sugar	Sugar	Cwt. Sugar	Sugar
Sugar beet* . .	349,000	24·4	426,000	5·7	525,000
		Tons		Tons	
Mangolds . .	328,000	19·1	6,265,000	1·6	6,790,000
Turnips and swedes	1,174,000	14·0	16,436,000	1·0	17,610,000
		Cwt.		Cwt.	
Hay—permanent .	4,932,000	20·6	5,080,000	9·0	7,299,000
temporary .	2,263,000	28·7	3,247,000	10·6	4,447,000

* 1930 acreage.

The lack of statistics of yield makes it impossible to estimate the increased yield that can be obtained by the use of fertilizers on rye, mixed corn, and other roots, including kale, cabbage, kohlrabi, market-garden crops, or fruit.

APPENDIX IX (*see Chapter VI*)

Fodder Requirements for Increased Live Stock

Cows.

The present number of cows (3·4 millions—average 1924–30) will be doubled. Each cow will require 0·9 acre of grazing land (see p. 69) during the summer. In winter 17 lb. hay, 1 lb. oat straw, and 20 lb. roots per day will be the daily maintenance ration.

Other Cattle.

The present number of other cattle, stated as the equivalent of 2-year-old beasts, is 2·9 millions. This number will be doubled. Each animal will require 0·9 acre of grazing land during the summer. In winter 10 lb. hay, 7 lb. oat straw, and 30 lb. roots will be required.

Sheep.

The number of sheep including lambs is 24 millions, equivalent to 19¼ millions full-grown sheep. Systems of sheep farming can be roughly classified thus:

(1) Sheep fed mainly on rough grazings.
(2) Sheep on lowland holdings fed mainly on grass.
(3) Sheep fed mainly on arable crops.

It is estimated that the number under (1) represents from 35 to 40 per cent. of the total. In class (2) it is estimated that there are 52 per cent. of the total and that the remainder are in class (3).

Sheep on the rough grazings are not included in these calculations.

Sheep in class (2), which will be increased from 10 to 20 millions, will require grazing at the rate of an acre to 6 sheep during the summer, unlimited grazing in winter and 1 lb. of hay per head per day for 56 days.

Sheep on arable land, the numbers of which will remain as now, will require fodder crops during most of the summer and roots in the winter as at present. Hay at the rate of 1 lb. per head per day for 112 days will be required.

Horses.

Horses will require ¾ acre for grazing and ¾ ton of hay.

Allocation of Available Acreage

	(Million acres)			
	Grazing	*Hay*	*Roots*	*Oat Straw*
Available	15·5	7·2	1·6	3·0
Cows will require	6·12	5·70	0·67	0·36
Other cattle	5·22	2·90	0·71	2·10
Sheep	3·33	0·36	0·20	
Horses	0·91	0·56		
	15·58	9·52	1·58	2·46

From this table it will be seen that the total acreage of grass available for grazing and for hay is 22·7 million acres, whereas 25·1 million acres are required. The 7·2 million acres of aftermath would more than supply the difference either as grazing, hay, or silage. There would be therefore more than sufficient fodder for winter and summer keep.

APPENDIX X (*see Chapter VI*)

Concentrated Food Requirements of the Increased Live Stock

An additional quantity of concentrated food will be required for the increased number of live stock kept. But the amount will be partially offset as the result of the better use of grass.

ADDITIONAL.

Dairy Cows. With cows doubled in number the total amount of milk produced for human food, as liquid milk, cheese, butter, and cream, dried and condensed milk, will be 2,660 million gallons. The demand for liquid milk (approximately 900 million gallons annually) is met by present supplies, and the extra milk will probably go for cheese and butter making.

The making of cheese and butter, which is done mainly from summer grass, requires only a small quantity of concentrated food. Where milk is made into butter less concentrates are fed than where liquid milk is sold wholesale or retail.

It is estimated that of the additional 1,330 million gallons of milk 443 millions will be produced in winter. For this winter production

an allowance of 3½ lb. concentrated food per gallon is made. Grass alone will provide for summer milk-production, leaving at most two months at the end of the season when additional food in the shape of concentrates may be needed by the cows. Allowance is made for these two months at the rate of 2 lb. concentrated food per gallon of milk.

Other Cattle. The number of other cattle will be doubled. Some are beasts fattening for the butcher, and most of the remainder are young cattle. For the fattening animals 4 lb. concentrated food per head per day for five months is allowed, and 1 lb. per head per day throughout the year for the animals under 1 year old.

Sheep. The sheep mainly fed on grass land will be increased by 10 millions. They will require ½ lb. concentrated food per head per day for four months.

Pigs. Pigs will be increased by 6 millions. Sows when suckling are allowed 10 lb. concentrated food per head per day. For the rest of the year they receive 2½ lb. per day. An allowance of 3 lb. per head per day will suffice for pigs other than breeding sows.

Poultry. The number of birds is increased by 50 millions. Each bird will need 2 oz. of grain and 1½ oz. of meal mixture per day.

SAVING.

In the foregoing estimates it has been assumed that grass is put to its fullest use. Early grass will lessen the amount of concentrated food needed by live stock. Farmers will also learn to use to greater advantage the grass they produce in summer. Credit, therefore, still remains to be taken for the utilization of these new sources of food by the existing live stock carried, and when this is done the additional concentrates required will be lessened accordingly.

SUMMARY.

Net increase in concentrates required

Corn	3,900,000 tons.
Offals	1,564,000 ,,
Cakes and meals . .	860,000 ,,

APPENDIX XI (*see Chapter VII*)

Composition and Digestibility of Dried Grass, Palm Kernel Cake, Undecorticated Cotton Seed Cake, Oats, Good Meadow Hay, and Alfalfa Meal.

	Dried Grass		Palm Kernel Cake		Undecorticated Cotton Cake (Egyptian)		Oats		Good Meadow Hay		Alfalfa Meal	
	Per cent.	*Digestibility. Per cent.*	*Per cent.*	*Digestibility. Per cent.*	*Per cent.*	*Digestibility. Per cent.*	*Per cent.*	*Digestibility. Per cent.*	*Per cent.*	*Digestibility. Per cent.*	*Per cent.*	*Digestibility. Per cent.*
Moisture ..	12·00	—	11·0	—	12·0	—	13·3	—	15·3	—	10·15	—
Crude protein	19·10	76·4	19·0	76	23·0	73	10·3	76	9·6	57	17·94	70
Ether extract	4·76	59·6	7·7	89	5·5	91	4·8	80	2·5	51	2·00	41
Fibre	16·17	79·2	13·5	39	21·0	37	10·5	28	26·0	59	14·13	42
Nitrogen-free extractives	38·01	76·9	45·5	83	32·7	61	58·0	76	40·5	64	42·28	72
Ash	9·96	—	3·3	—	5·8	—	3·1	—	6·1	—	13·50	—
Lime (CaO)	0·97	—	0·30	—	0·30	—	0·15	—	1·0	—	1·97	—
Phosphoric Acid (P_2O_5)	0·77	—	1·1	—	2·50	—	1·30	—	0·5	—	0·77	—
Starch value	51·5		75		42		60		31		49	
Protein equivalent ..	14·0		17		17		7·5		4·5		12·6	

NOTE.—*Starch Value* (Kellner) = the number of pounds of pure digestible starch, equivalent for production of energy or for storage as fat, to 100 lb. of the foodstuff.

Protein Equivalent = the number of pounds of pure digestible protein equivalent, in value, to the nitrogen substances in 100 lb. of the foodstuff.

APPENDIX XII (*see Chapter IX*, p. 134)

Balance Sheet of Nitrogen and Mineral Foods supplied to and used by the Plant

	Amounts applied lb. per acre			*Amounts removed lb. per acre*		
	N	P_2O_5	K_2O	*N*	P_2O_5	K_2O
Roots	*55*	*85*	*107*	130	43	222
Spring corn	23	46	23	51	20	42
Seeds	46	..	..	67	22	78
Wheat	46	46	23	71	30	41
Total applied in artificial fertilizers	*170*	*177*	*153*			
Total applied in 12½ tons farmyard manure	131	42	181			
	301	*219*	*334*	319	115	383

N = Nitrogen. P_2O_5 = Phosphoric acid. K_2O = Potash.

The rotation and yields used in calculating the above figures are as follow:

1st year:

One-third potatoes yielding 8·5 tons per acre
One-third swedes and turnips yielding 16·0 ,, ,,
One-sixth sugar-beet yielding 10·5 ,,
One-sixth mangolds yielding 22·5 ,,
Tops returned direct to soil.

2nd year: *Per acre*

One-half oats yielding 17·2 cwt. grain, 25·8 cwt. straw.
One-half barley yielding 18·8 ,, ,, 22·0 ,, ,,

3rd year:

Seeds 40·0 ,, hay.

4th year:

Wheat 22·8 ,, grain, 40·0 ,,

APPENDIX XIII (*see Chapter X*, p. 152)

Marrow Stem Kale Experiment, Jealott's Hill

1929

Treatment	*Tons per acre*	*Crop increase over no Nitrogen*
No nitrogen	9·52	—
2 cwt. nitrogen fertilizer . .	15·30	5·78
4 ,, ,, ,, . .	18·87	9·35
6 ,, ,, ,, . .	21·93	12·41

1930

Treatment	*Tons per acre*	*Crop increase over no Nitrogen*
No nitrogen	11·16	—
3 cwt. nitrogen fertilizer . .	12·82	1·66
6 ,, ,, ,, . .	16·22	5·06
9 ,, ,, ,, . .	18·15	6·99

1931

Treatment	*Tons per acre*	*Crop increase over no Nitrogen*
No nitrogen	12·82	—
3 cwt. nitrogen fertilizer . .	17·56	4·74
6 ,, ,, ,, . .	22·64	9·82
9 ,, ,, ,, . .	24·80	11·98

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